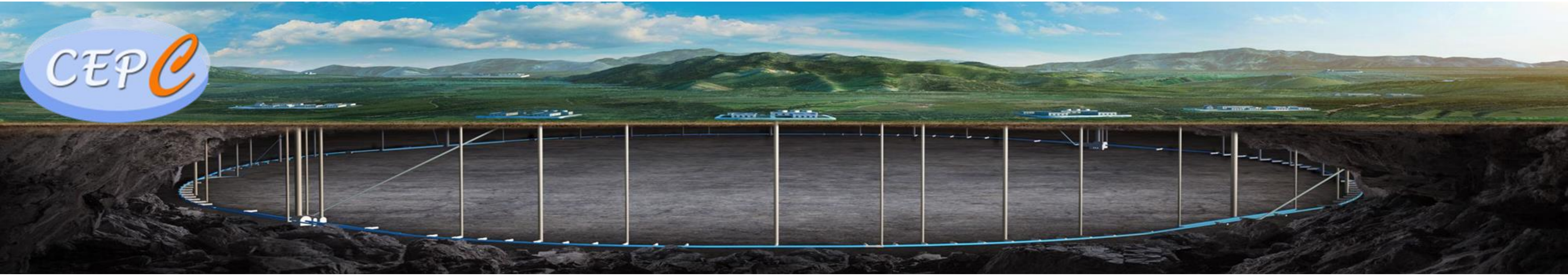

CEPC Large Scale Measurement, Precision Alignment and Efficient Installation Studies in EDR

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On behalf of CEPC Alignment and Installation Group

HKUST-IAS HEP Conference
Jan. 22-25, 2024, Hongkong

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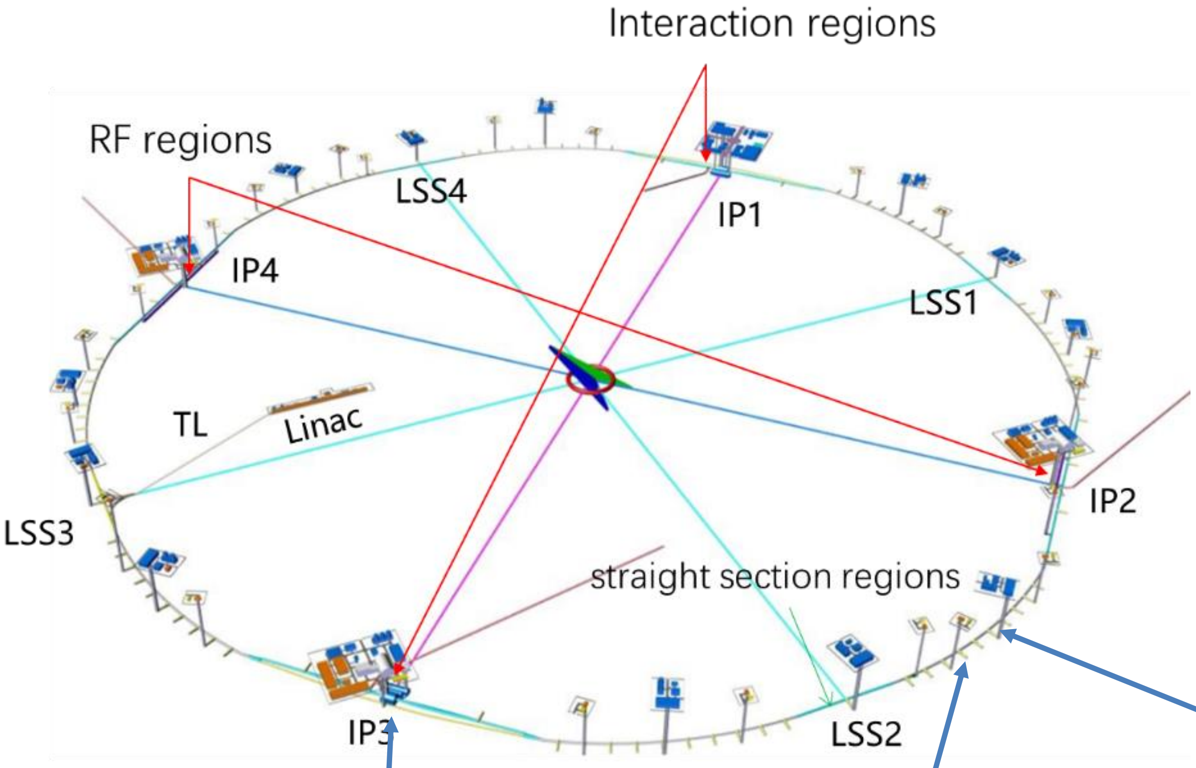
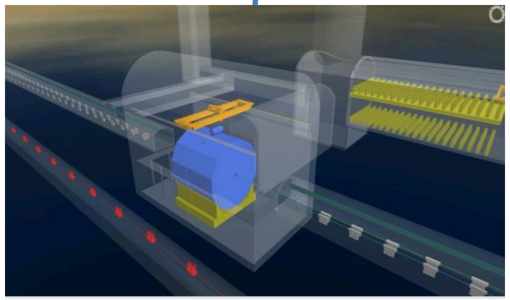
1、Introduction

Alignment scope

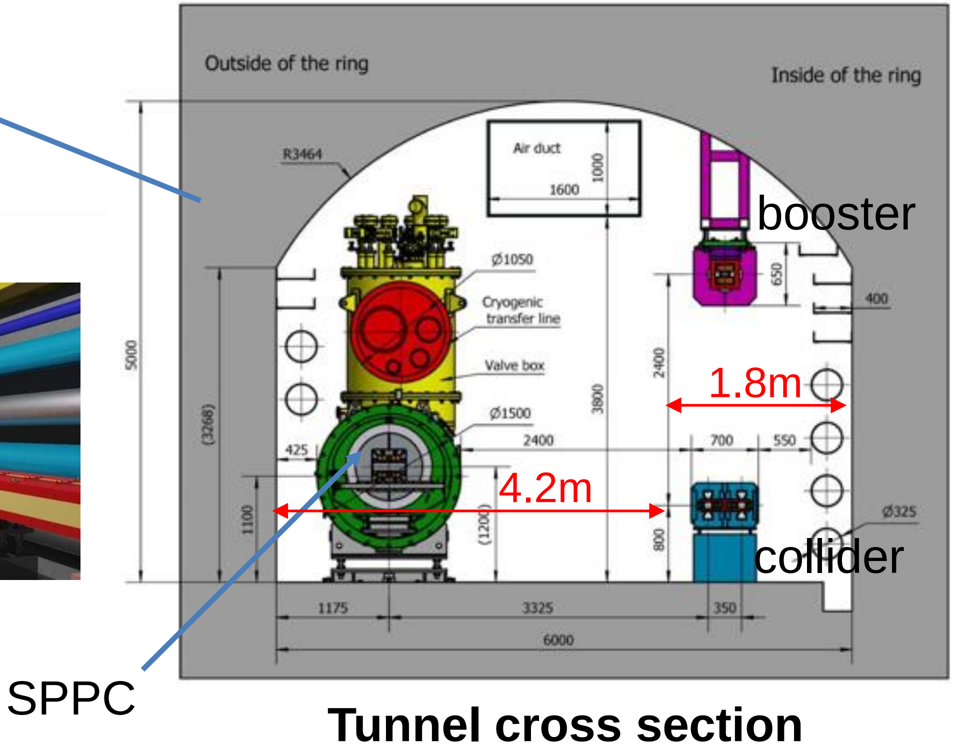


Linac: 1.6km
TL:1.5km
Circumference of ring tunnel:100km
Collider: 100km
Booster: 100km
Tunnel cross section: 6X5m



Interaction region

Ring tunnel



Tunnel cross section

1、Introduction

- Quantity of components

Component	Collider Ring	Booster	Linac, DR, TL	Total
Dipole	16258	14866	135	31259
Quadrupole	4148	3458	714	8320
Sextupole	3176	100	72	3348
Corrector	7088	2436	275	9799
BPM 、 PR 、 DCCT 、 kicker	3544	2408	180	6132
Septum Magnet	68	32	2	102
Kicker	8	8	2	18
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	34396	23320	2008	59724

1、Introduction

- Alignment accuracy requirement

Relative position accuracy requirement of adjacent components （1 σ）						
Component	Transversal/mm	Vertical /mm	Longitudinal/mm	Roll /mrad	Pitch /mrad	Yaw /mrad
Dipole	0.1	0.1	0.15	0.1	0.2	0.2
Quadrupole	0.1	0.1	0.15	0.2	0.2	0.2
Sextupole	0.1	0.1	0.15	0.2	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
IR Solenoid	0.2	0.2	0.3	0.5	0.5	0.5

1、Introduction

- Key issues of CEPC alignment

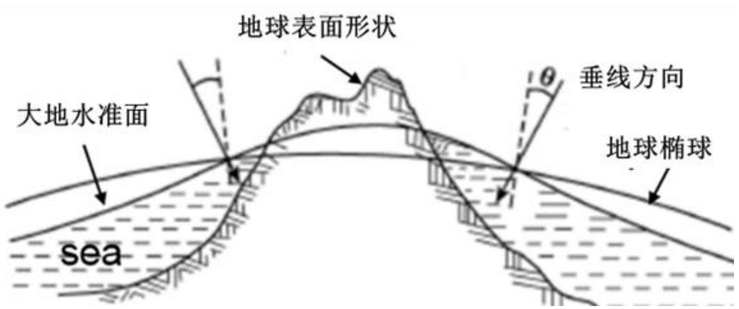
1. For large scale measurement, it must consider the irregular undulation of the geoid and needs to carry out geoid refinement.
2. Establishing control network to provide reference frame for component alignment and control error accumulation.
3. To improve alignment and installation efficiency, it is necessary to R&D high efficiency measurement method, and optimize the installation plan.
4. To cope with ground motion, temperature change and instability influence, we need to carry out smooth alignment, periodical survey and alignment and position monitoring.

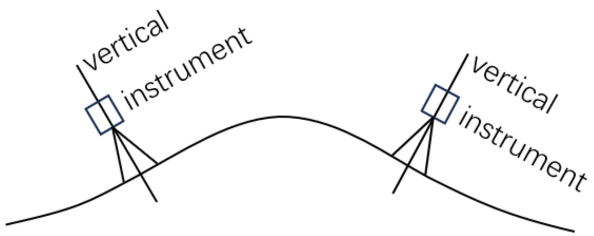
1、Introduction

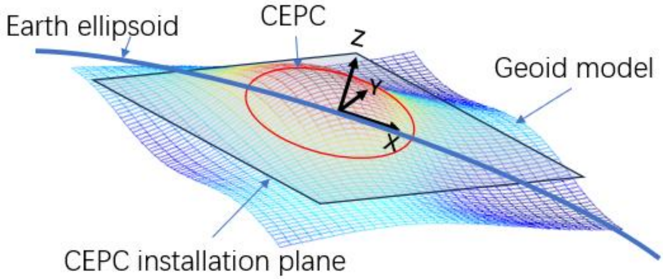
CEPC alignment

1. Geoid refinement.
2. Establish alignment control network.
3. Component fiducialization and pre-alignment.
4. Installation alignment.
5. Smooth alignment.
6. Position monitoring and machine maintenance alignment.

2、Geoid refinement



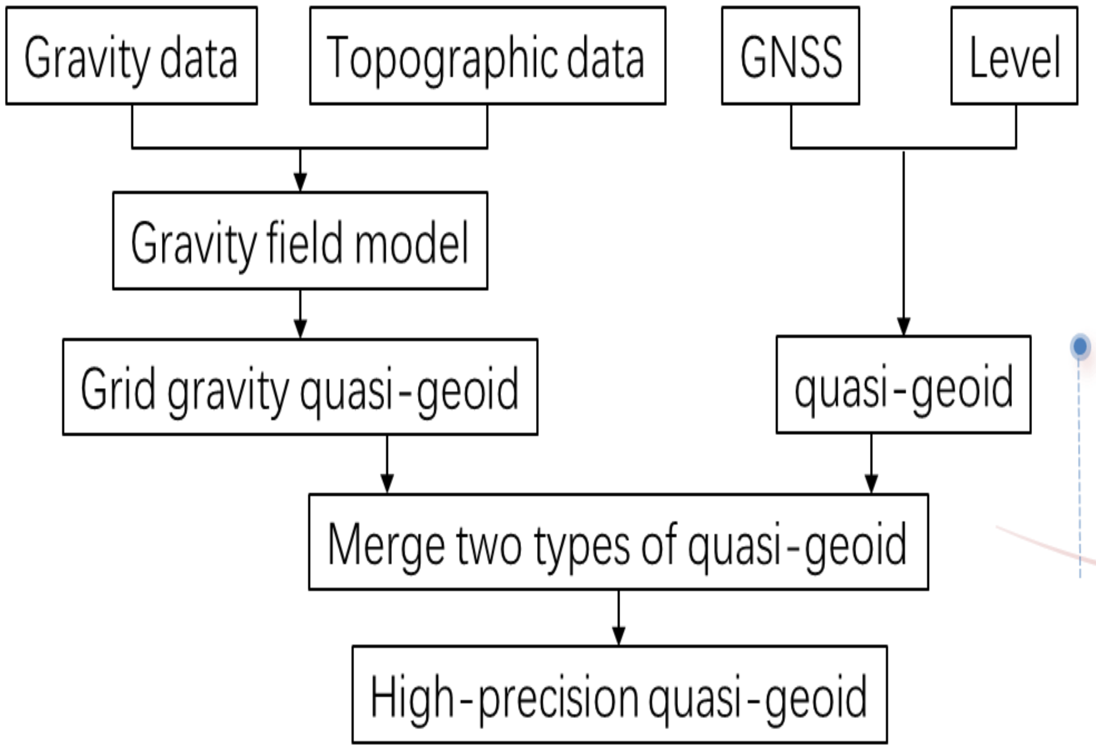


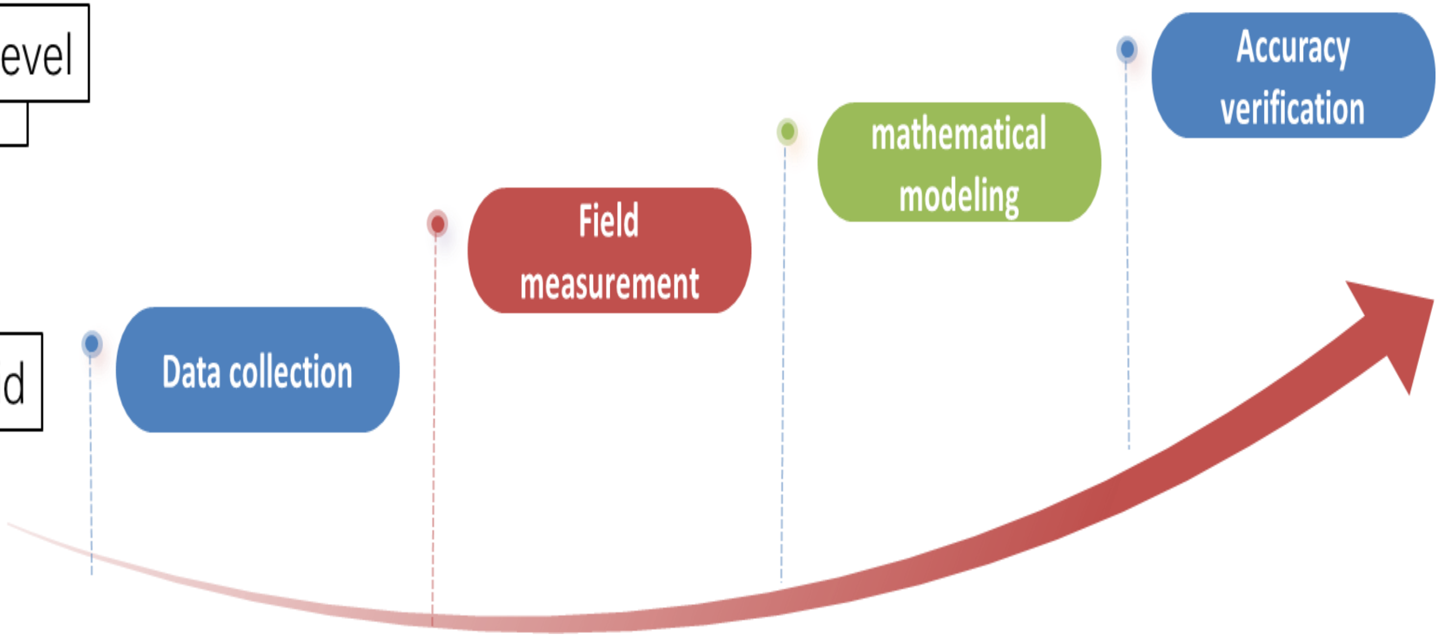


- The Earth's surface is irregular, and conducting measurements on its surface requires using the geoid as a datum.
- CEPC will be installed reference to a plane, so it is necessary to accurately determine the position relationship between the irregular geoid and the installation plane through the geoid refinement.
- Goal：To build a quasi-geoid model with 10mm elevation anomaly accuracy and 1″ vertical deflection accuracy.

2、Geoid refinement

- Geoid refinement plan

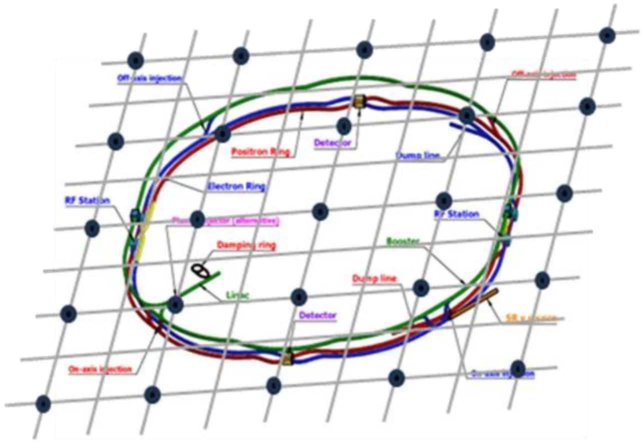




2、Geoid refinement

- Data collection: Collecting gravity data within a 300km radius of CEPC. Carry out supplementary measurement in areas lacking gravity data.

- Field survey:
  - Build 25 observation points in a range of 32km×32km covering the CEPC area. The observation points will be distributed in a grid pattern with a distance of 5-10km.
  - On each observation point performing GNSS, level, and vertical deflection measurement.



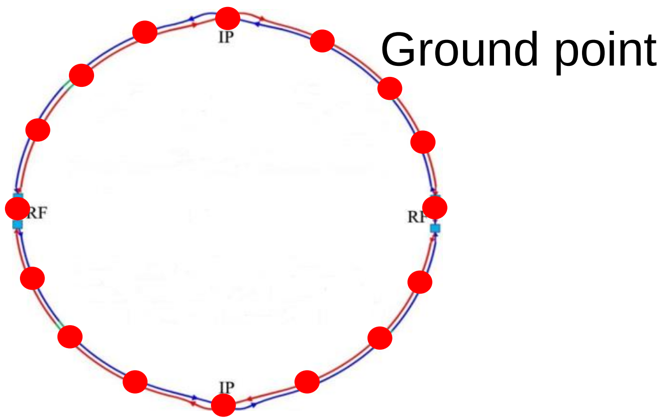
- Mathematical modeling:
  - Using the collected gravity data and EIGEN6C4 according to the Stokes-Helmert method to calculate the gravity quasi-geoid.

2、Geoid refinement

- Using the topographic data SRTM DTM, applying removal-restoration principle, according to Airy-Haiskanen model to do the gravity anomaly topographic equilibrium reduction.
- Applying the second type Helmert agglutination method to calculate the gravity quasi-geoid.
- Using spherical crown harmonization analysis method jointly solve GNSS level, vertical deflection observations and the gravity quasi-geoid, then get the resolution 2’×2’ grid quasi-geoid model.
- Model transformation: The quasi-geoid model is based on the ground measurement data and needs to be transferred to the tunnel elevation. The model transformation is a very challenging work, needs further research the theory and the measurement method.

2、Geoid refinement

- Geoid model accuracy verification
  - ➢ Elevation anomaly verification: GNSS and level measurement.
  - ➢ Vertical deflection verification: vertical deflection measurement.
- The goal of geoid refinement is very challenging, we need to carry out geoid refinement experiment to further the study.



Geoid refinement schedule

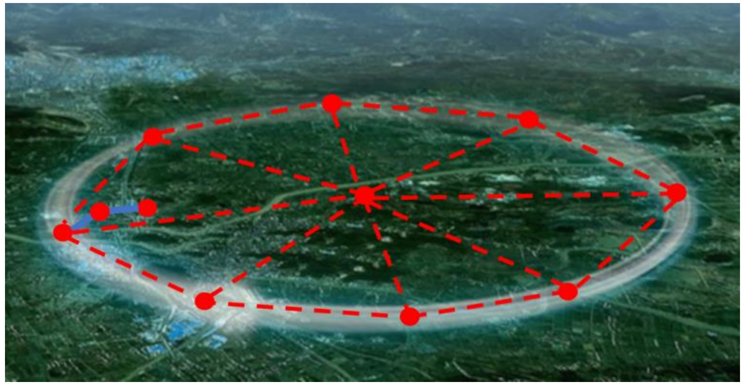
Month	1	2	3	4	5	6	7	8
Site survey								
GNSS								
Level								
Vertical deflection								
Gravity								
Data processing								
Accuracy verification								

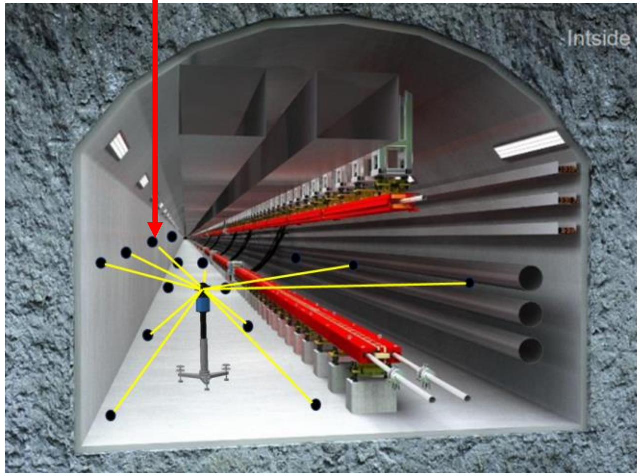
- Personnel, workload and time estimation

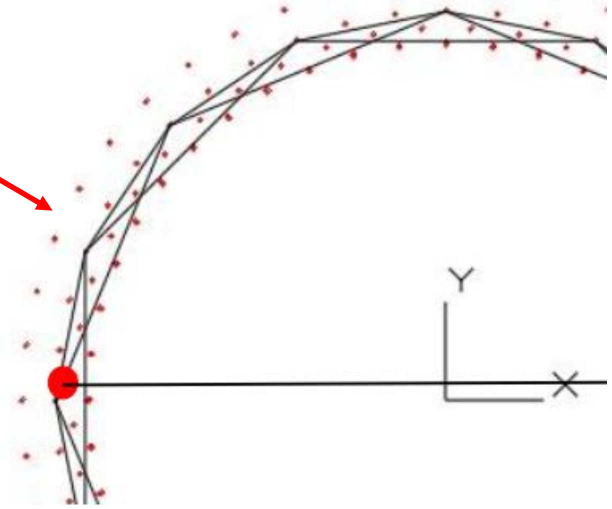
Work content	Instrument（number）	Group× (number of people / group)	Workload	Week
Site survey	Pick-up truck (4)	4× (4)	800km^2	8
GNSS	GS10+AR20 (16)	16×(2)	25 points	2
Level	DNA03 (8)	8×(4)	480km	6
Vertical deflection	Hangguang zenithal camera（1）GNSS receiver（1）	1×(4)	25 points	8
Gravity	CG6（1）LCR（1）、GNSS receiver（2）	2×(4)	Depend on site selection	
Data processing	Desktop computer（8）	1×(8)		8
Accuracy verification	GS10+AR20 (16)、DNA03(5)、zenithal camera (1)	1×(24)	16 points, 100km	8

3、CEPC alignment control network

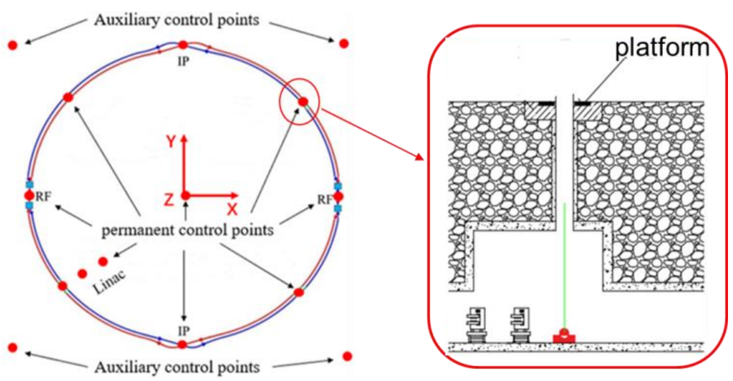
- Control network： provide an unified location reference frame for CEPC alignment and control the error accumulation；
- 3 levels control network
  - Surface control network
  - Backbone control network
  - Tunnel control network



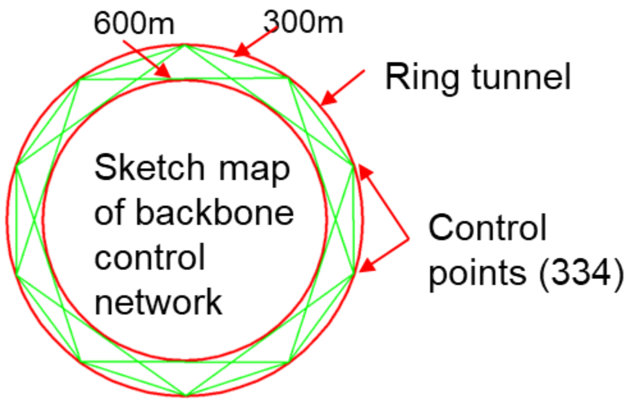




3、CEPC alignment control network

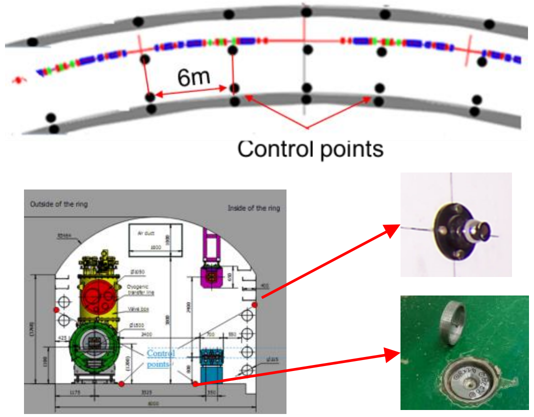


Surface control network



Backbone control network

More than 18800 sections

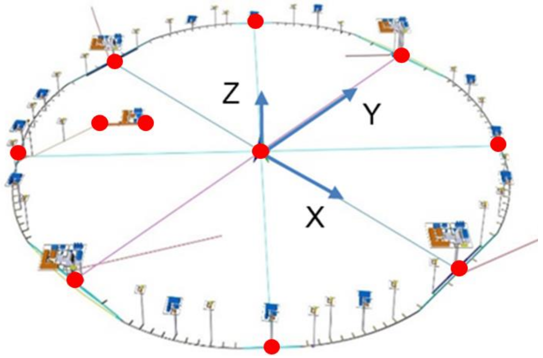


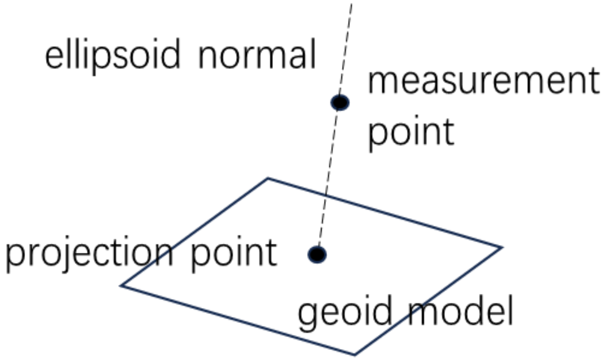
Tunnel control network

	Instrument（number）	Personnel	Month	Accuracy
Surface control network	GNSS(16), level(8)	32	1.2	Planar: 7mm Elevation:5mm
Backbone control network	Total station(8), level(8), gyro-theodolite(1)	32	1	Planar: Standard error 3.85mm(12.5km). Relative error 0.79mm(300m). Elevation: : Standard error 2.5mm(12.5km), Relative error 0.35mm(300m).
Tunnel control network	Laser tracker(16)	32	6	Planar: Standard error 0.35mm(300m) . Relative error 0.065mm(6m) Elevation : Standard error 0.38mm(300m) . Relative error 0.074mm (6m)

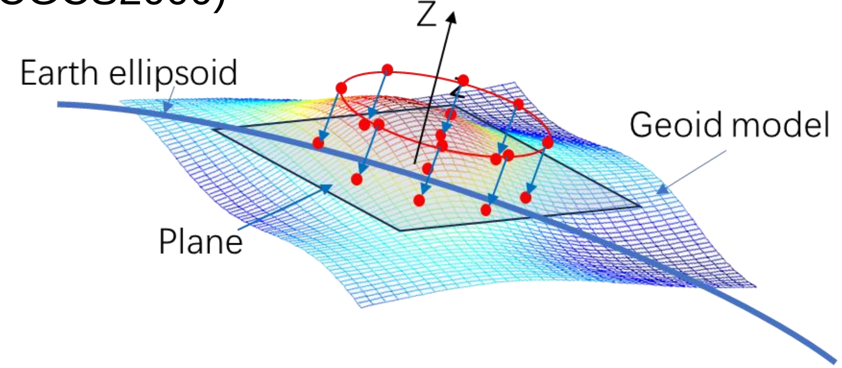
CEPC coordinate system

- Establish CEPC coordinate system





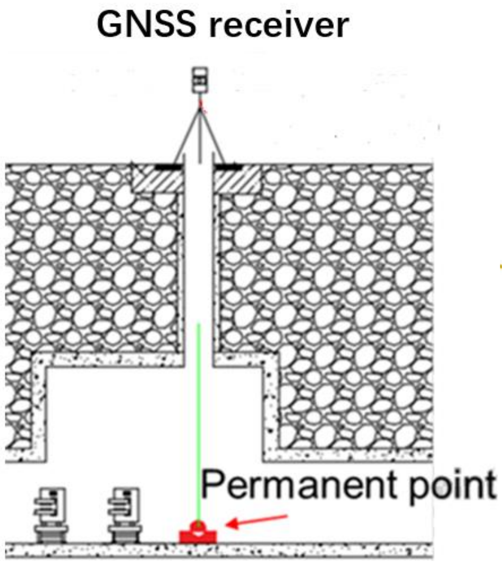
China Geodetic Coordinate System 2000 (CGCS2000)

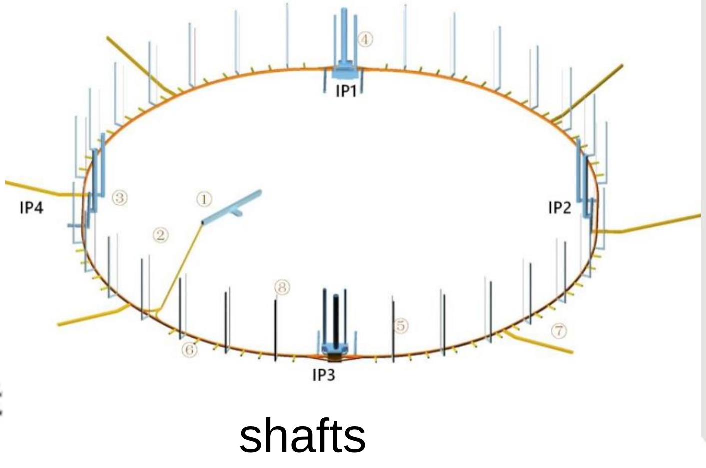


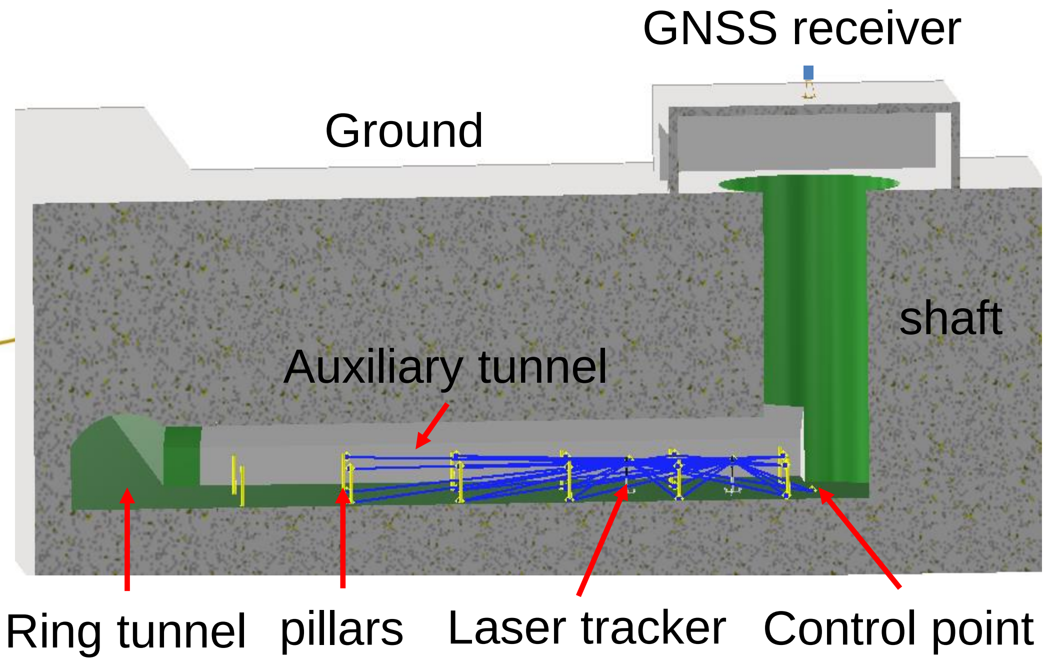
- The XY plane is best-fit with the geoid, its normal is the Z direction.
  - Projecting the surface control netwrok points onto the quasi-geoid, fit a plane with these projection points.
  - Using the normal of this plane as the Z axis of CEPC coordinate system.
- Using the ring center point as the origin, a point to determine the X axis, a coordinate system can be established.
- By coordinate system transformation, the XY plane can be moved to the specified height to get CEPC coordinate system and the transformation parameters between CGCS2000 and CEPC.

3、CEPC alignment control network

- Surface control network ground and tunnel connection measurement:
  - GNSS measurement must be carried out on the ground.
  - The connection measurement between the ground and the tunnel can be carried through boreholes or shafts.

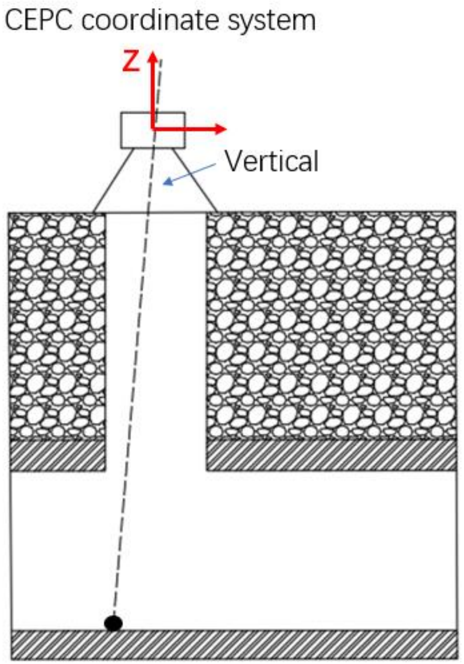






3、CEPC alignment control network

- Connection measurement:
  - Measurement instrument is centered to the control point along the vertical.
  - It needs to calculate the coordinate difference between the ground point and the tunnel control point.
  - The distance D from the ground point to the tunnel control point can be measured by using a tape, a steel wire or a total station.

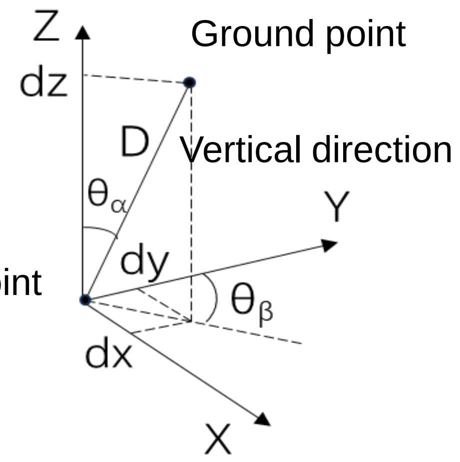


transit square

borehole

According the vertical direction of the ground point and the distance D to calculate the coordinate differences

CEPC coordinate system



Accuracy: 0.5mm/(100m, 1arcsec.)

$$\begin{cases} dx = D\sin\theta_\alpha \cos\theta_\beta \\ dy = D\sin\theta_\alpha \sin\theta_\beta \\ dz = D\cos\theta_\alpha \end{cases}$$

4、Tunnel installation alignment

- project period is :3 years and 9 months

- Tasks:
  1. Control network construction.
  2. Control network measurement
  3. Support position setting out and installation
  4. Component installation and alignment.
  5. Smooth alignment

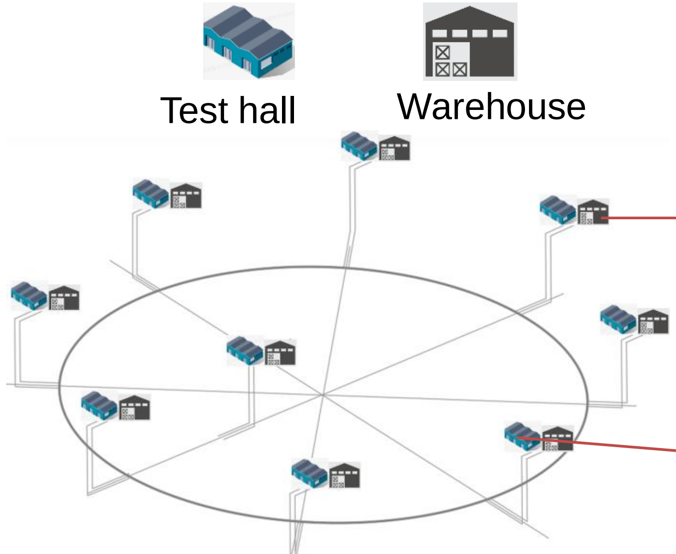
- Using the tunnel control network and laser trackers to perform components installation alignment.

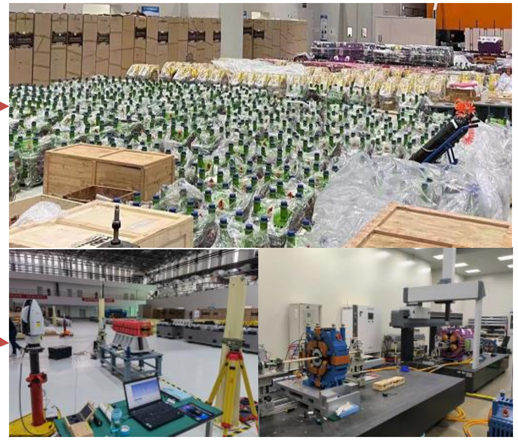
- Various vehicles and hoisting machineries will be needed.

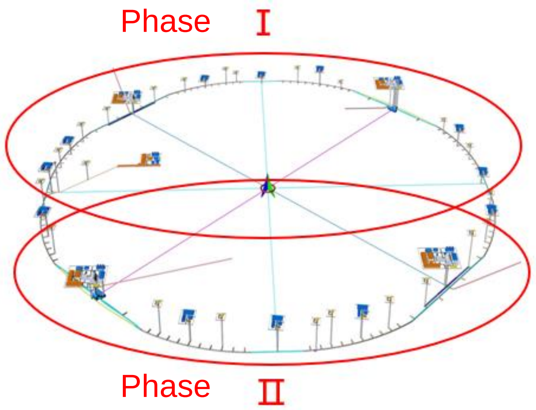
- Smooth alignment: Due to ground motion, temperature change and other factors, machine occur deformation will be inevitable. So, after the initial installation and alignment, it is necessary to carry out 2~3 times smooth alignment.

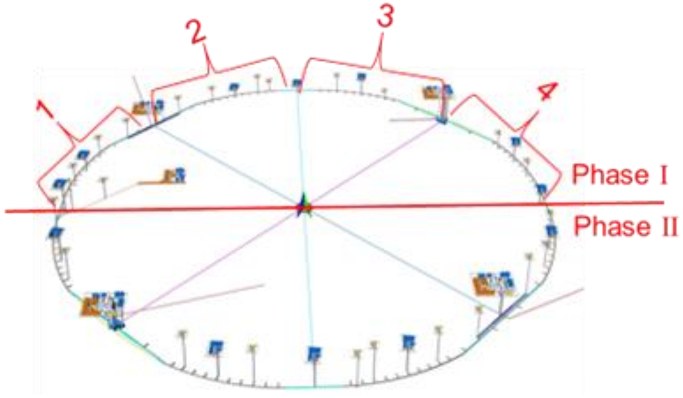
4、Tunnel installation alignment

- To improve installation efficiency a segments parallel strategy is adopted.





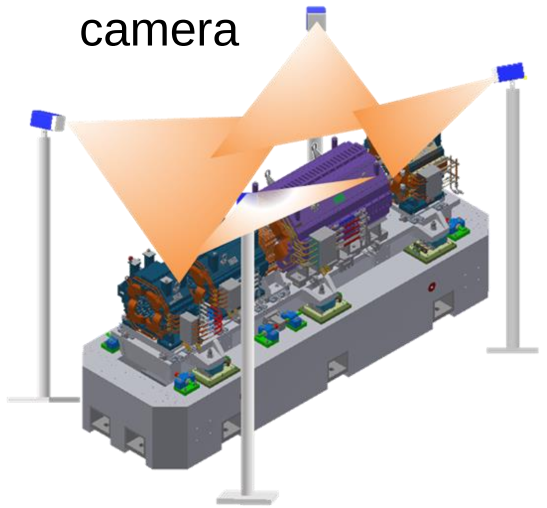




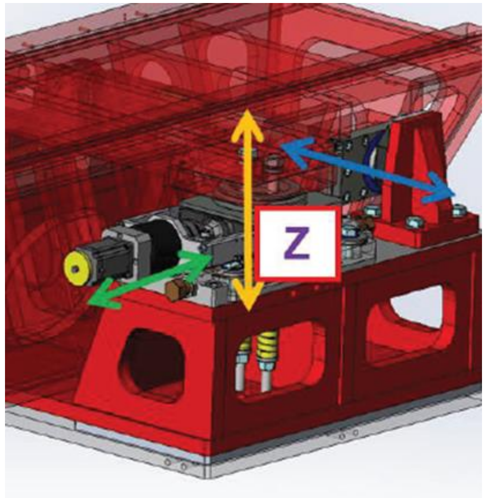
Ring tunnel installation plan

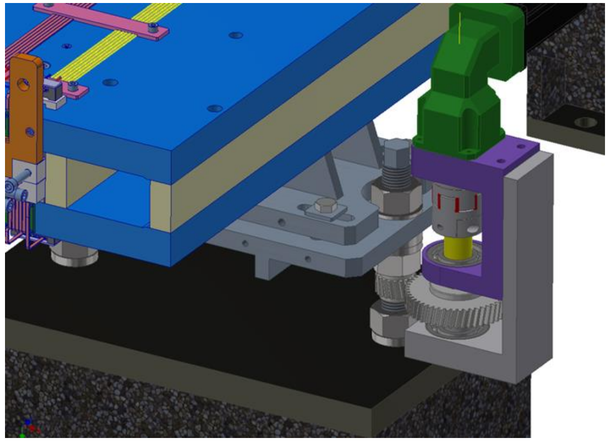
Phase	Group	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ⅰ	16	Network construction																																													
	16	Network measurement																																													
	16	Support setting out																																													
	16	Support installation																																													
	32+32	Component installation																																													
Ⅱ	16	Network construction																																													
	16	Network measurement																																													
	16	Support setting out																																													
	16	Support installation																																													
	32+32	Component installation																																													
	64	Smooth alignment																																													

4、Tunnel installation alignment



High accuracy measuring field





Motor-driven adjustment mechanism

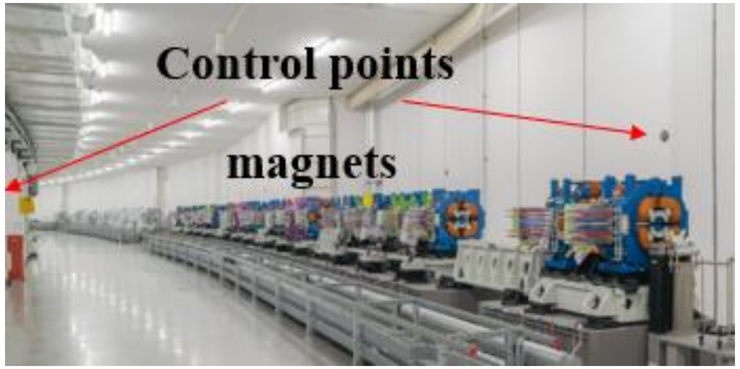
- Moveable universal automated adjustment platform.
  - High accuracy measuring field to provide the component position feedback.
  - Motor-driven adjustment mechanism to adjust the component according to the position data.

5、Visual instrument measurement experiment

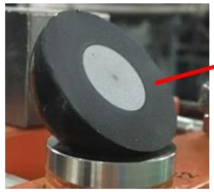
- Visual instrument
- A portable visual instrument has been developed.
- Advantage :
  - ➢ Multiple points can be measured at once.
  - ➢ It can improve the success rate of data processing and measurement accuracy.
- Objective: high accuracy, high efficiency measurement.

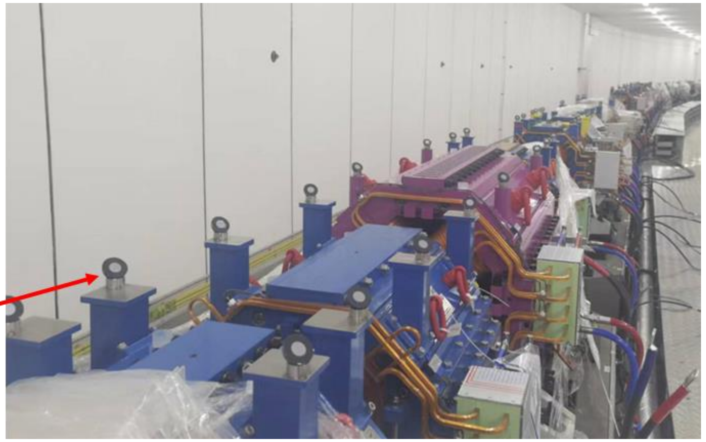
5、Visual instrument measurement experiment

- In Dec. 2023, a measurement experiment was conducted in HEPS storage ring.



- Paste encoded targets on the wall for image match and point recognition.
- Hemisphere targets for control points and magnet fiducials measurement.





5、Visual instrument measurement experiment

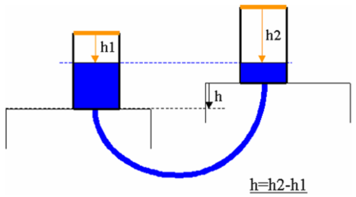
- The range of the measurement experiment is half of the ring and took 10 days, 4 times faster than using a laser tracker.
- Adopt set up station measurement method. Each station the visual instrument is leveled, and the horizontal and vertical angles of each picture were measured. A total of 250 stations were measured, approximately 20~30 pictures were taken in each station.
- The observations are being processed.

6、Deformation and solutions

- For CEPC such large-sized machine, it occurs deformation will be inevitable.
  - Conduct survey during the annual shutdown period to find where occur the deformation.
  - Install monitoring system.

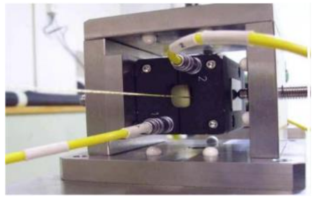
Settlement monitor

Hydrostatic Levelling System (HLS)



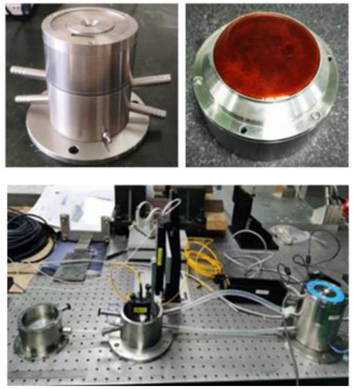
Component transversal and vertical monitor

WPS



Picture from CERN

  - Capacitive hydrostatic level sensor developed for HEPS



- Due to cost consideration, the monitoring sensors will not be installed evenly throughout the entire ring. We plan to install them in the MDI which has higher alignment accuracy requirement.

Summary

- Geoid refinement plan is studied for large scale measurement. The goal is very changeling, need to carry out experiment to further the study.
- To provide position reference frame and control error accumulation, a three levels control network has been designed, and the connection measurement plan between ground and tunnel is designed.
- To improve installation efficiency, a segments parallel strategy is adopted. A new kind measurement instrument is under R&D, and the first time measurement experiment has been performed.
- To cope with deformation, a smooth alignment strategy will be applied, and the monitoring systems will be install in MDI. Detailed MDI alignment plan need to be researched in the future.

Thank You !