CEPC Survey and Alignment

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Oct. 9-12, 2018, IWAA2018 Fermilab

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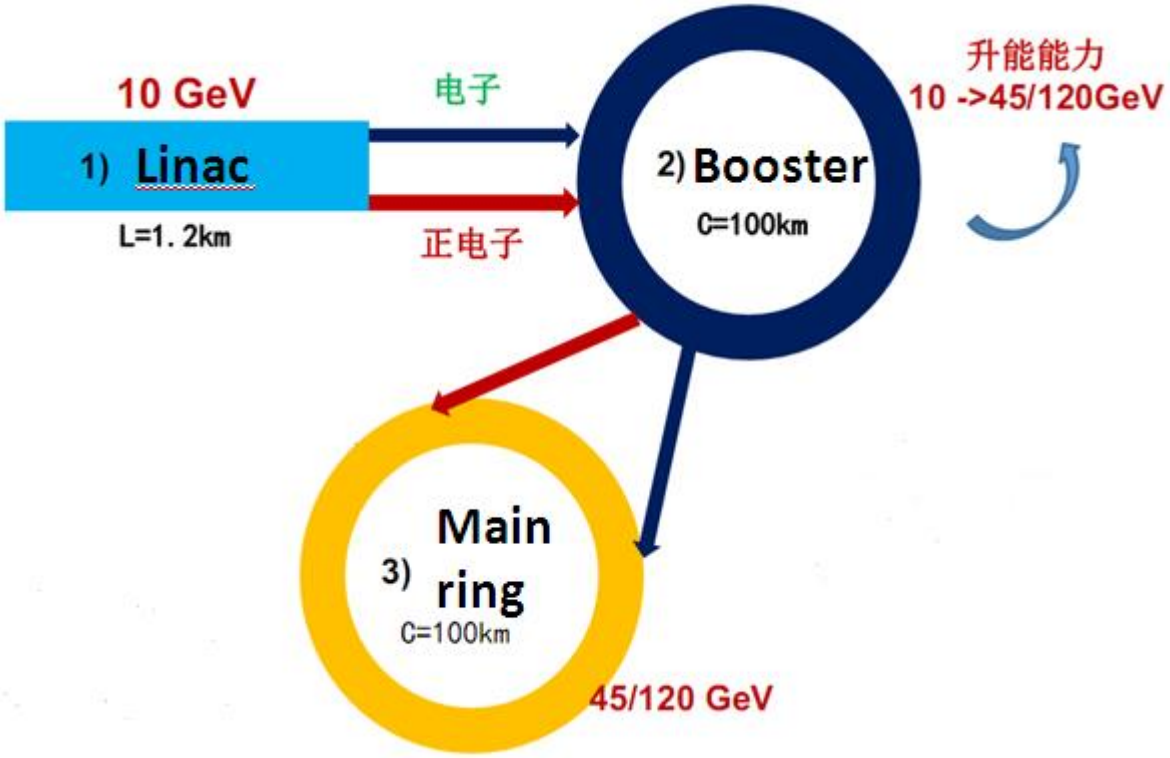
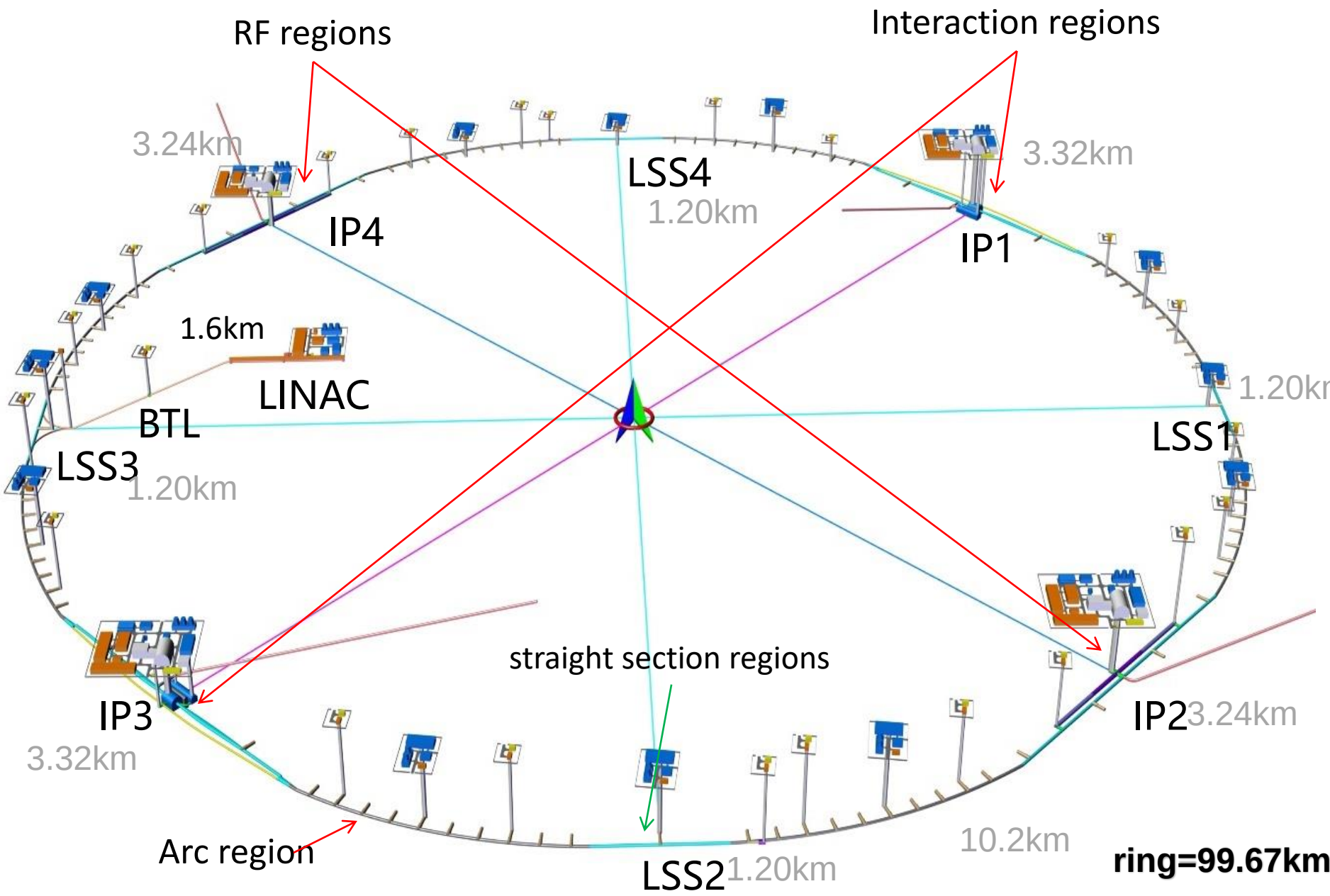
1、Introduction

- Circular Electron Positron Collider (CEPC) is a huge particle collider aim to measure the precise properties of the Higgs boson which was discovered at CERN by LHC.
- First proposed in 2012, after several times argumentation and modification its conceptual design report is finished in June 2018.
- CEPC is designed to run at beam energy 120GeV for seven years to generate over a million Higgs bosons then it will be operated at 45.5GeV for two years to generate ten billion Z bosons as well as run at 80GeV for a year to produce around 15 million pairs of W+ and W-.

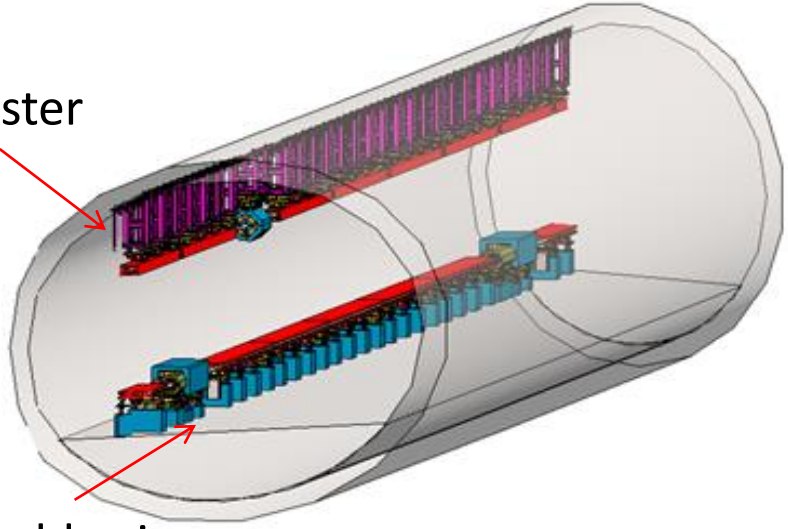
- The ideal construction schedule is from 2022 to 2030.
- Following a decade of studying the Higgs, Z and W bosons, it is hoped to begin construction a proton-proton collider inside the existing tunnel in 2040.



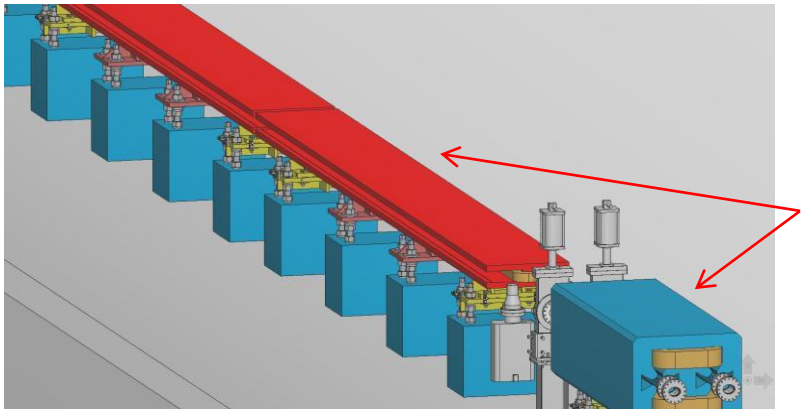
CEPC General Layout



- Ring tunnel has a double-ring and a booster.
- Booster is hung on the top of tunnel about 3.2m above floor.

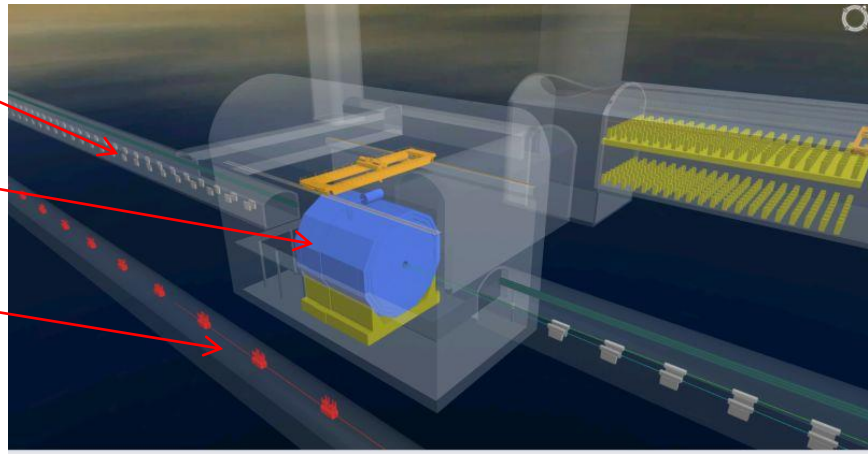


Ring tunnel model



Interaction region

- In interaction region there are two tunnels one is for booster the other is for main ring.



Site selection

Changchun, Jilin

Qinhuangdao, Hebei

Huangling, Shaanxi

Huzhou Zhejiang

Shenshan, Guangdong

Where to build CEPC is decided by what kind of support from the local government we will receive in terms of ,for example, laboratories, living conditions, roads and power supply.

S&A Overview

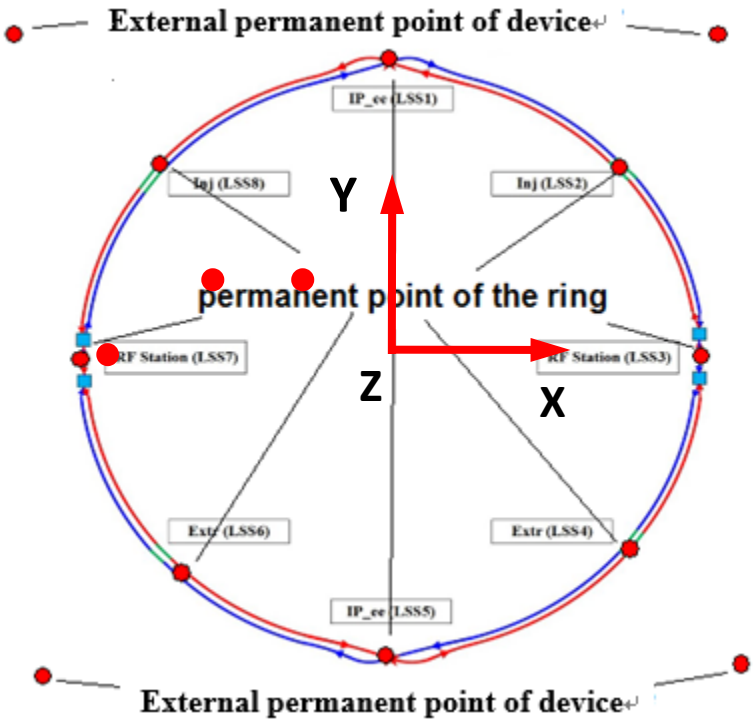
- Survey and Alignment group(S&A) is responsible for CEPC components position alignment and maintenance.
- work will be carried out in two phases.
- The first phase is carried out in CEPC construction period. Align all of the components to the designed geometric positions within a certain precision，provide an initial orbit for CEPC commissioning.
- The second phase is in CEPC stop periods, the beam will be a benchmark and according to the beam requirement to do orbit smooth alignment.

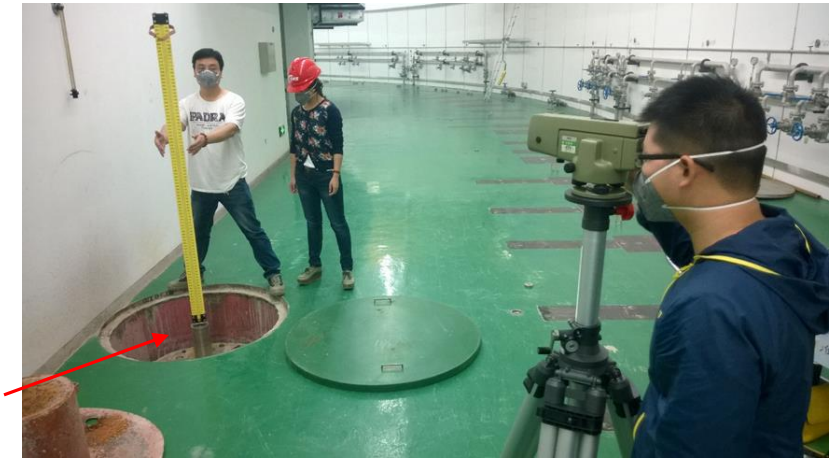
- Ultra-long CEPC circumference brings two challenges to S&A
- Improve working efficiency: put in more work teams and instruments, R&D advanced technologies.
- Accidental error accumulation of ultra-long narrow tunnel control network and its accuracy control.
- S&A work can be divided into 4 parts:
- Alignment control networks survey
- Components fiducialization and pre-alignment
- Tunnel installation alignment
- Components segmentally smooth alignment

2、CEPC Control Network Design

- Control networks provide an unified location reference frame for the whole accelerator and control the error accumulation of survey and alignment.
- For the ultra-long CEPC we designed a 3 levels control network.
  - Surface control network
  - Backbone control network
  - Tunnel control network

- Surface control network provides the absolute position control for CEPC and high precision constraint datum for tunnel control network.
- Composed of 16 permanent points (4 external points and 12 internal points)
- 2 points locate Linac, 2 points locate LTB, 8 points locate ring.
- These 12 internal points will be built in CEPC tunnel, they are a part of the tunnel control network.





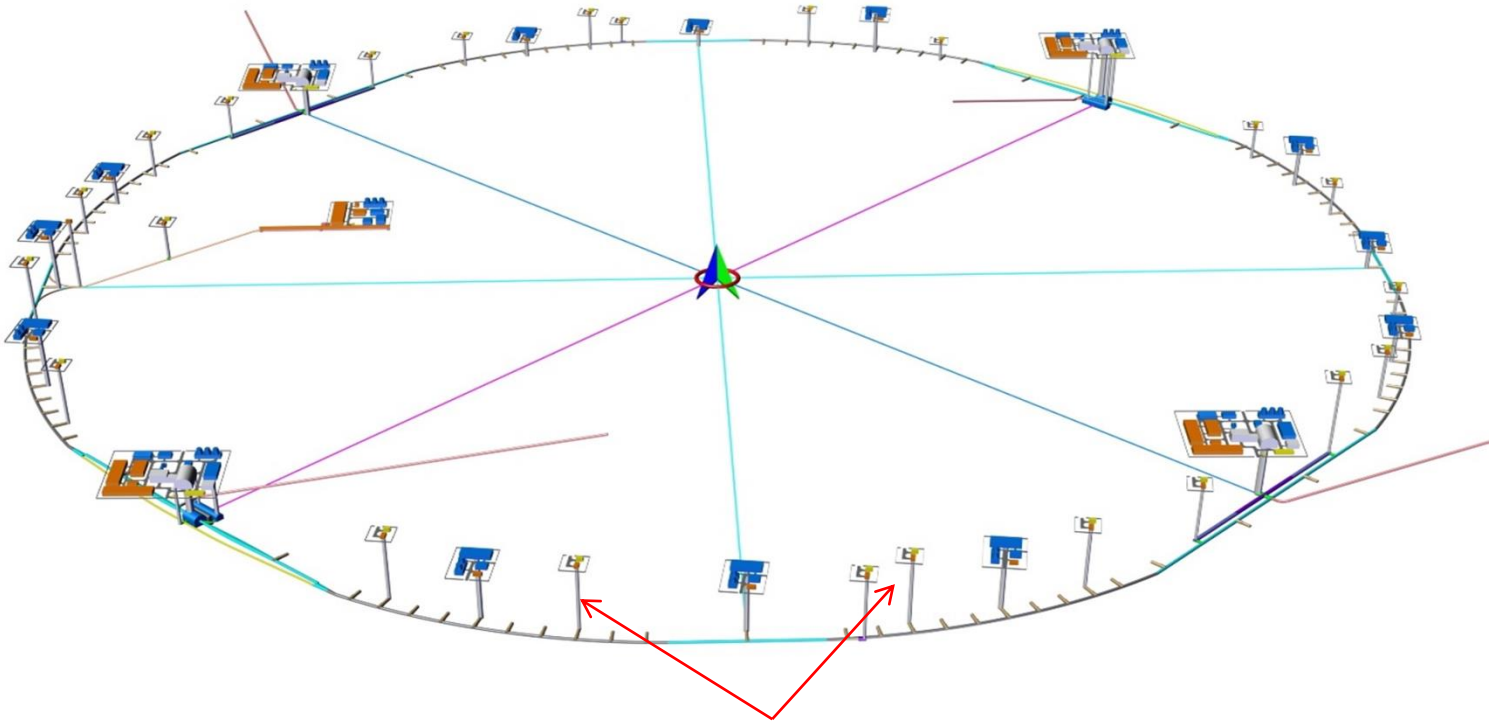
Tunnel permanent point

- The pillars of tunnel permanent points are built on the base rock
- Shield from soil with steel tube.

Monument can hold 1.5’’ half ball target/ reflector

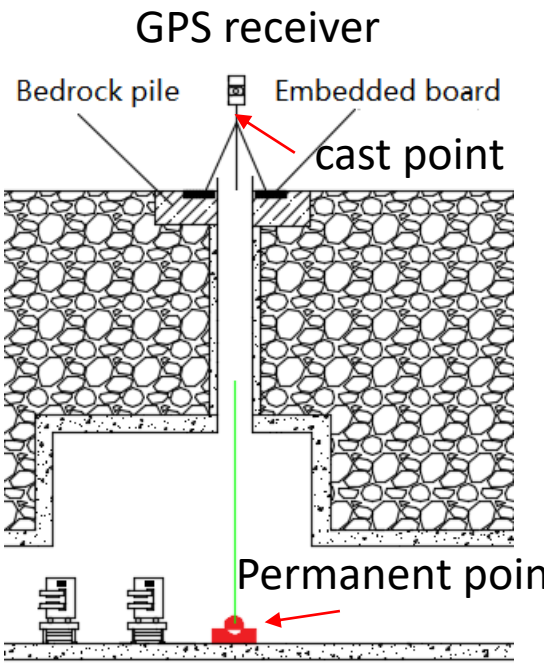
External control point can be measured by GPS

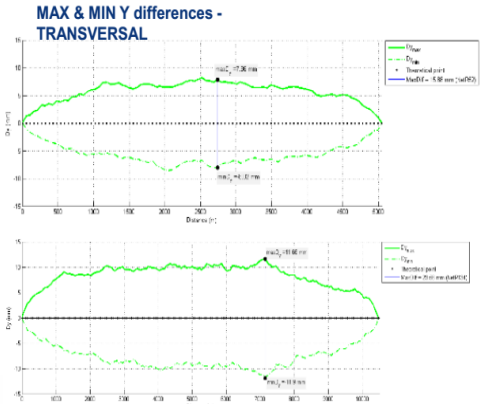
- There are many shafts link the tunnel and ground surface, we can use these shafts to measure the tunnel permanent points from ground



Shafts

- Use GPS and level measure the surface network
- Permanent point in tunnel can be plumbed to a cast point on the ground through the shaft.
- The measurement accuracy of surface network is about 10mm in horizontal direction and about 7mm in vertical direction.
- Component absolute accuracy depends on the distance between two adjacent permanent points.
- CSNS 210m Linac transversal maximum deviation is 0.15mm.
- CERN simulation result shows 8mm for 5km and 12mm for 10km.



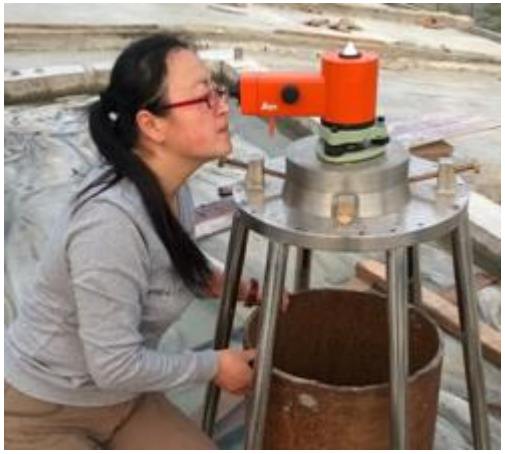


Instruments and software for Surface network survey

LEICA GS10

AR20 + LGO software

LEICA NA2 + SHANWEI software



LEICA Wild NL

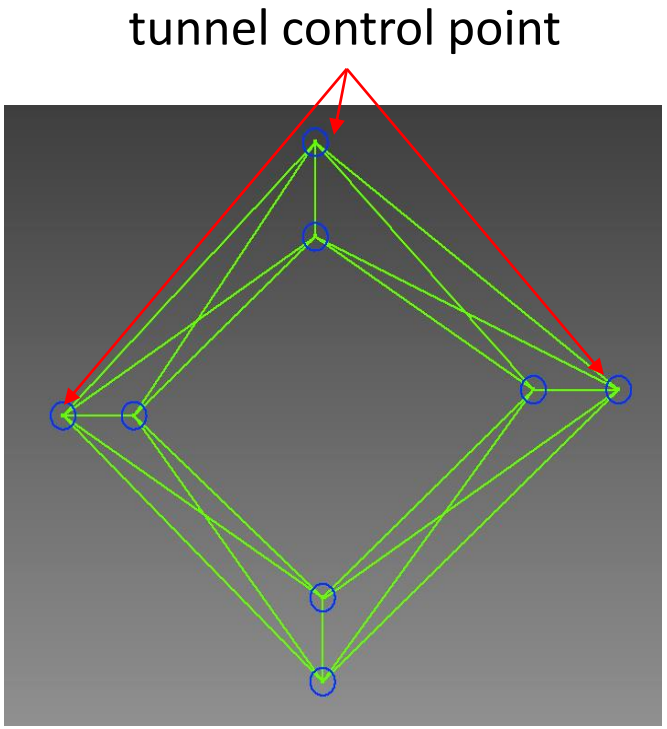
LEICA AT401

Tape

- The height between GPS and tunnel permanent point can vary from tens of meters to two hundred meters depends on where CEPC will be built.
- According to our experience of CNSN, where the biggest height is 30 meters, using Wild NL, the plumb accuracy is 0.5mm. The height can be measured by AT401.
- If the height is too big, we plan to use a transit square to plumb point and use a total station to measure the height.

Total station

- Backbone control network
- Strengthen the tunnel control network，reduce error accumulation.
- It is a kind of large span double-traverse structure control network.
- Points of adjacent sections must be intervisible and the distance should be as long as possible
- Use total stations to carry out backbone network survey.

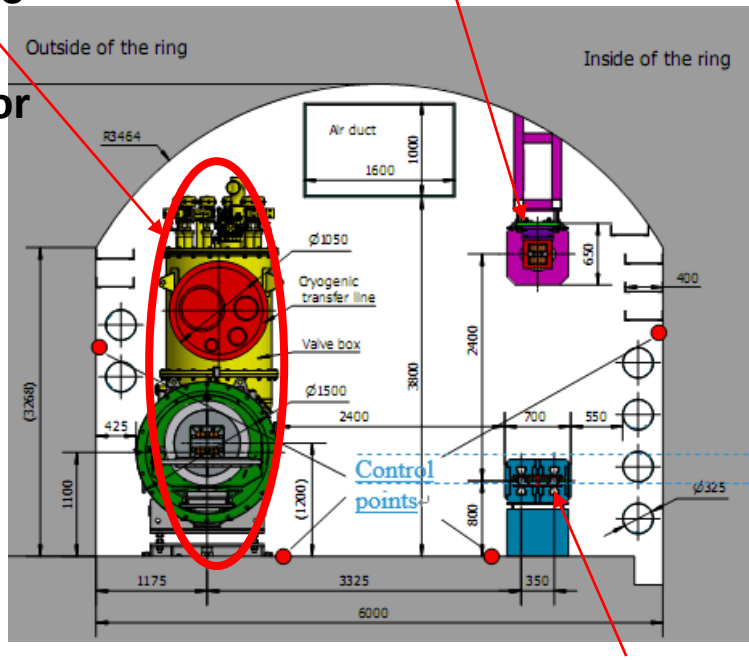


Backbone control network

- Tunnel control network is a position reference of components installation and alignment.
- tunnel control network along CEPC tunnel will be evenly distributed with an interval of 6 meters, each section there are 4 control points, two on the floor, one on the outer wall and one on inner wall.
- Use laser trackers and levels carry out tunnel network survey

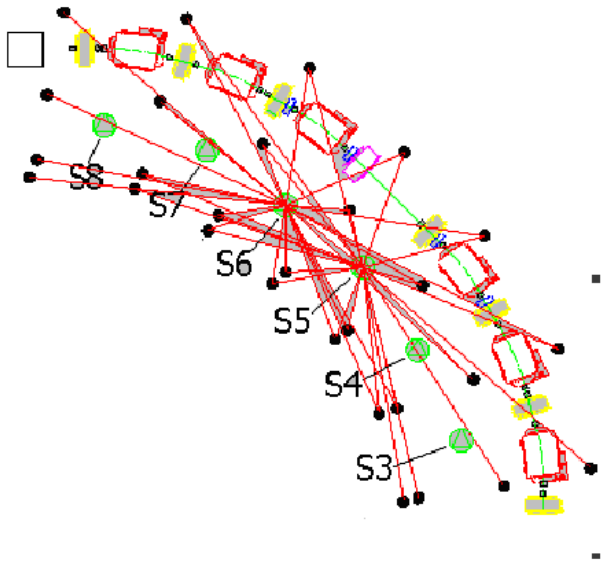
Future upgrade to a Proton accelerator

Booster

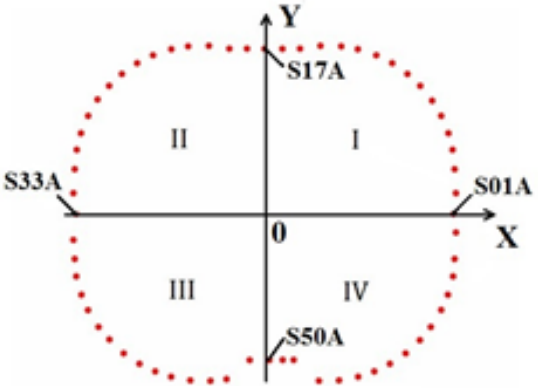


Tunnel cross-section view

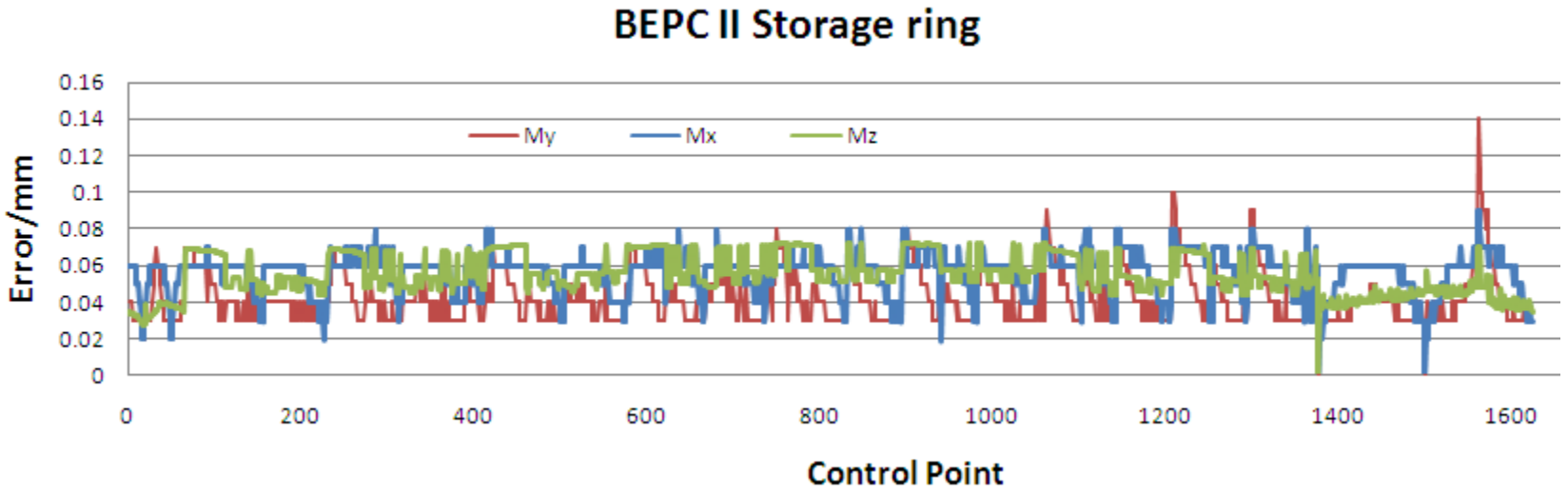
Double-ring



BEPCII



- BEPCII 237.53m ring the point measure error is better than 0.08mm.(2006,2008,2010,2012)



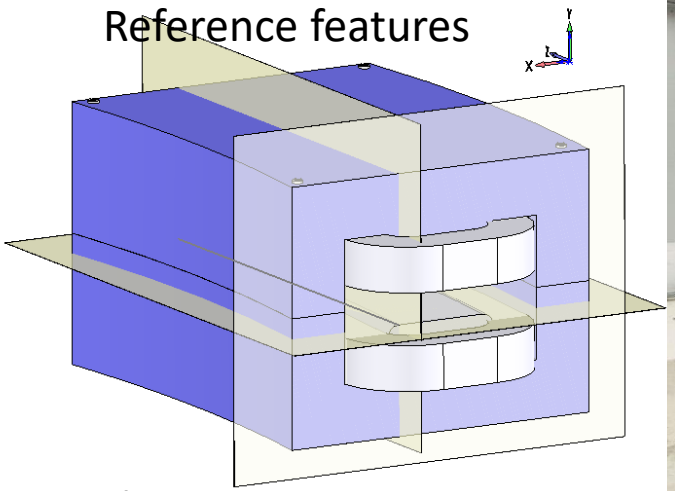
- Control points much denser than CEPC
- The point measure accuracy of CEPC is about 0.12mm

3、Component fiducialization and alignment

- Component fiducialization is to draw the beam center to its fiducial points, then the fiducial points coordinates can be transferred to CEPC global coordinate system and used for component tunnel alignment
  - Laser tracker
  - Articulated arm
  - Photogrammetry

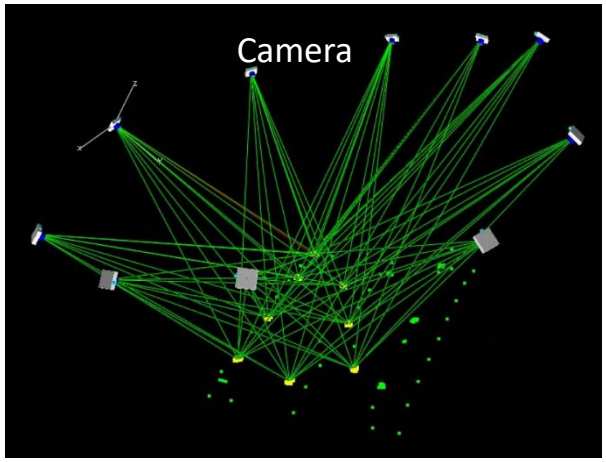
The precision of components' fiducialization is about 0.05-0.10 mm.

Get boundary dimensions
Reference features



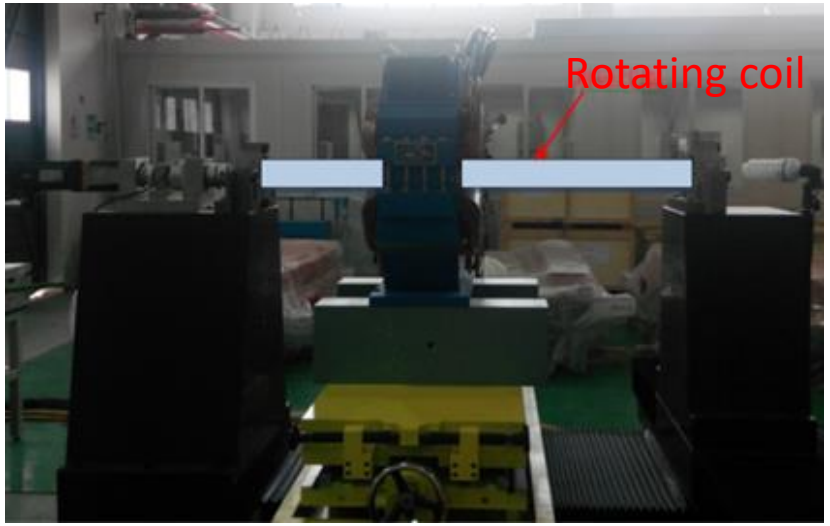
Dipole Magnet
Fiducialization Datum Planes

Bunching cavity Fiducialization with Articulated flexible arm



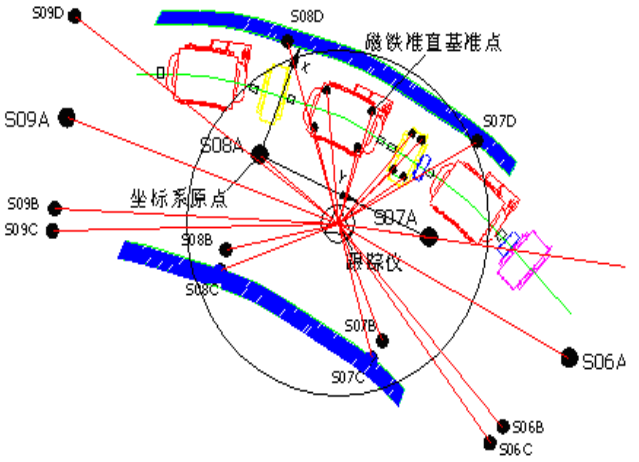
Photogrammetry measurement

- Optical instruments Level, Transit square, electronic gradienter are also necessary.

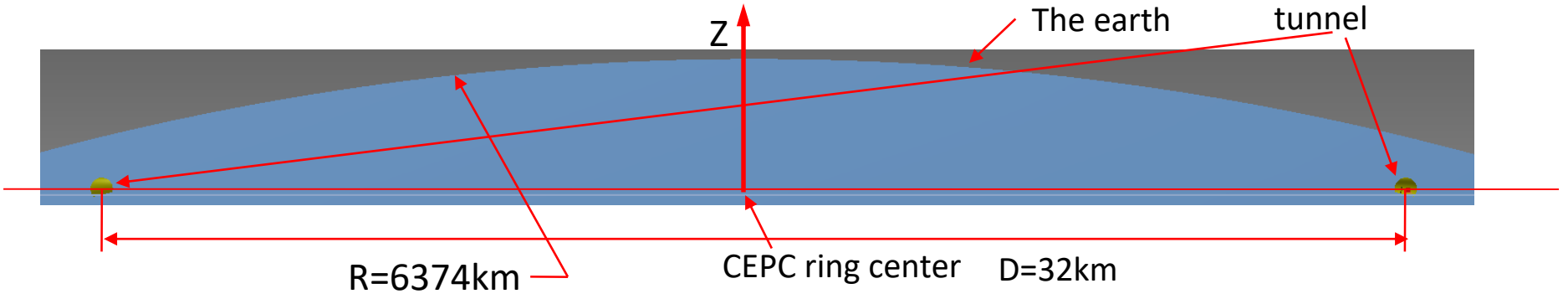


- To improve magnet fiducialization accuracy, we will use magnetic center measurement substitute mechanical center measurement.

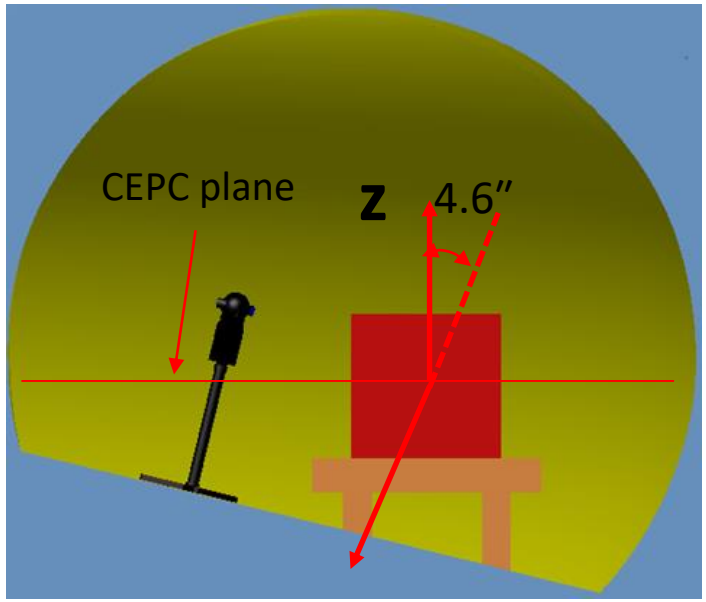
- We use the tunnel control network and laser trackers to perform tunnel components alignment.
- Measure the tunnel control network and through best-fit to determine the laser tracker position in CEPC global coordinate system.
- Using laser tracker measure the component fiducial points to obtain the component position.
- Adjust the component to the required tolerance.
- After the initial installation, we will carry out an overall survey, best-fit the result with the nominal coordinates to find the large deviations then do smooth adjustment.
- Components tunnel alignment accuracy is about 0.15~0.25mm.



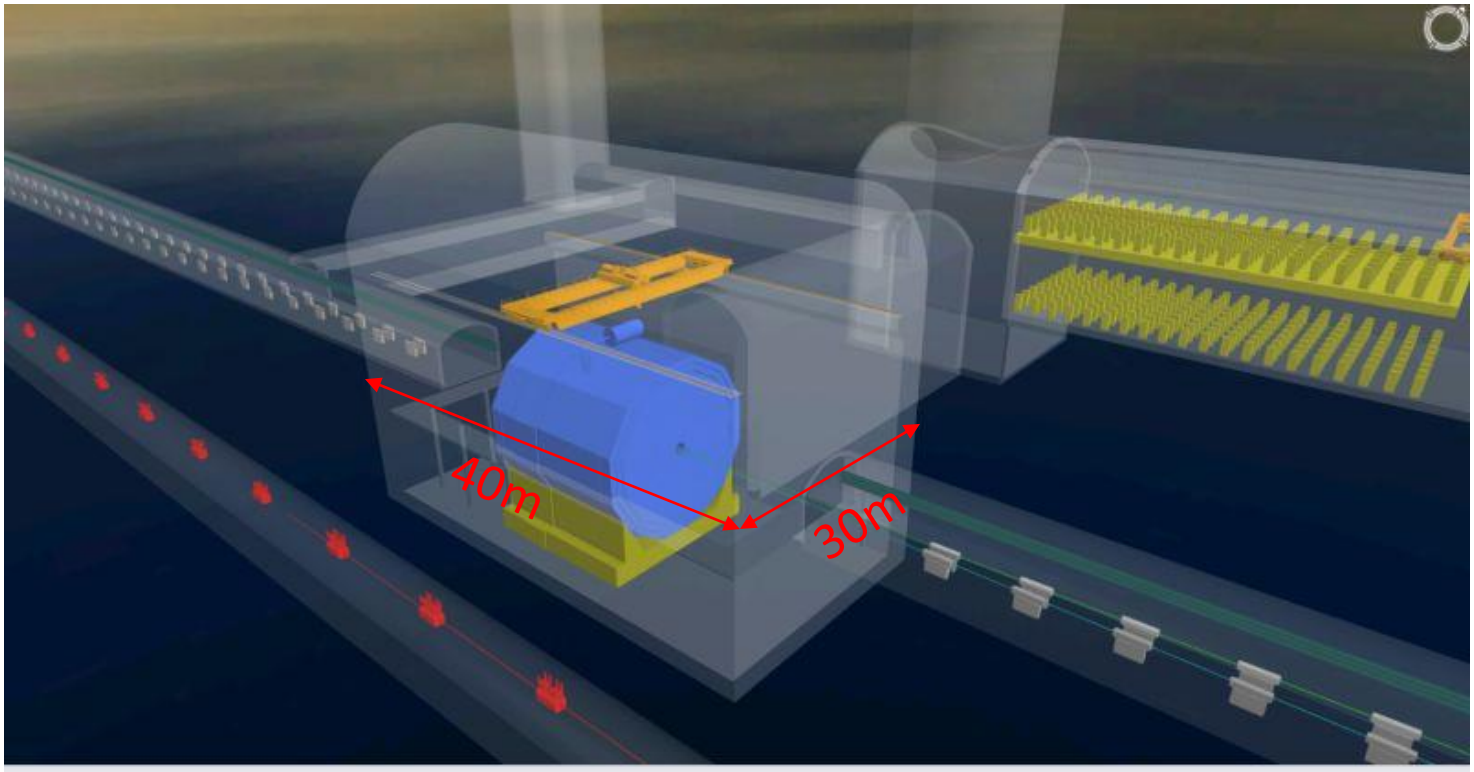
- CEPC should be built on a plane, its normal direction is Z.
- The earth is an ellipsoid, its gravity directions along the CEPC tunnel are not parallel with the Z.



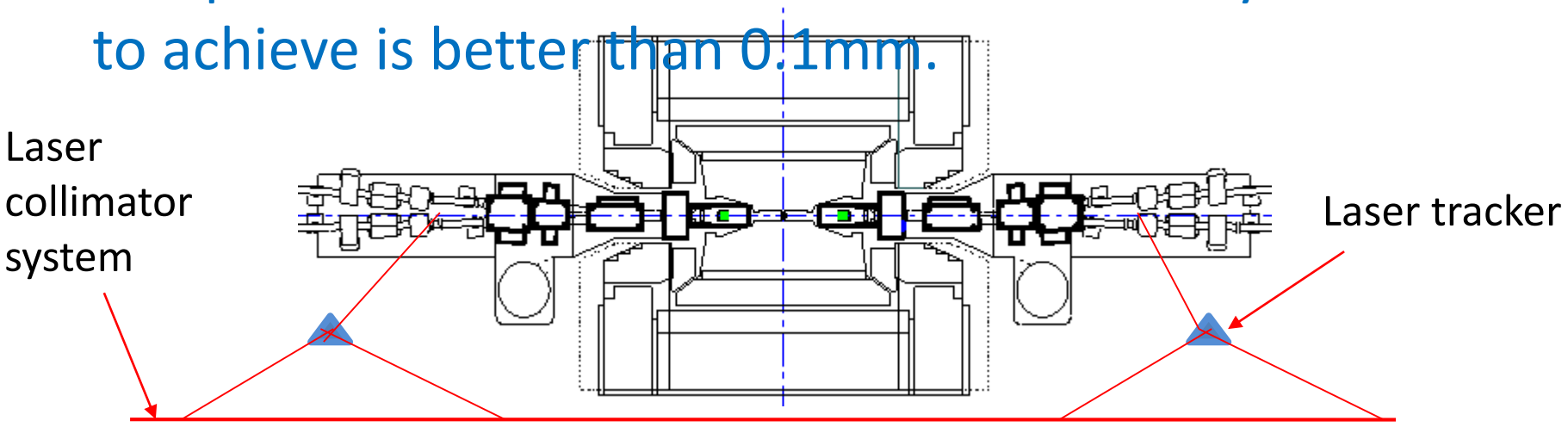
- The angle between Z and tunnel local gravity direction is about 4.6″
  - In tunnel components will be not perpendicular to the ground.



- Interaction region alignemnt
  - Alignment in the interaction region will be much more demanding than in the Arcs due to the extremely low β-functions.
  - At present we have not detailed structure design of interaction region. The detector hall is 40mX30m, the detector is about 14mX15m.



- The basic strategy is using laser trackers to do a rough alignment first, then use a laser collimator system to carry out the refined alignment, which can reach high precision and suitable for straight section alignment.
- We will install a laser collimator system beside the detector . Using laser trackers and control network align the laser parallel with the nominal beam orbit. Then we can use the laser as a reference align all the components to the beam orbit. The accuracy we want to achieve is better than 0.1mm.



■ Monitoring system

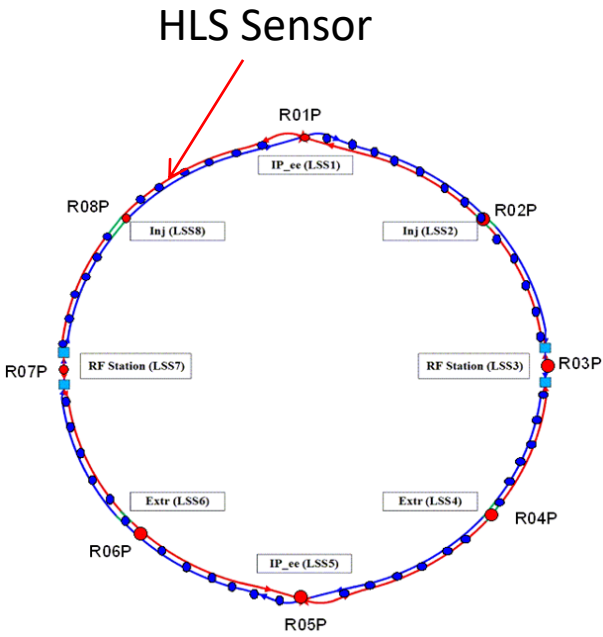
Settlement monitor

- ➢Hydrostatic Levelling System(HLS)
- ➢HLS sensors will be installed on the ground near the components.
- ➢Every 300-500m will be equipped with a sensor along the tunnel
- ➢Accuracy ±0.01mm

Component transversal and vertical monitor

- ➢Wire Positioning System (WPS)

HLS



Calibration facilities

- Temperature & Humidity laboratory
- 60m calibration bench
- Laser interferometer
- Coordinate Measuring Machine
- Tool microscope

4、Alignment precision requirement

Provide by physics group

Component	Transversal /mm	Vertical /mm	Longitudinal /mm	Pitch /mrad	Yaw /mrad	Roll /mrad
Dipole	0.1	0.1	0.15	0.2	0.2	0.1
Quadrupole	0.1	0.1	0.15	0.2	0.2	0.1
Sextupole	0.1	0.1	0.15	0.2	0.2	0.1
Corrector	0.1	0.1	0.15	0.2	0.2	0.1

Alignment precision statistic

	Fiducialization /mm	Control network /mm	Measurement /mm	Adjustment /mm	Totall /mm
Component	0.05~0.1	0.12	0.05	0.05~0.1	0.15~0.2

- To meet the requirement, it needs to do some improvements
  - Fiducialization, use Coordinate Measuring Machine, magnetic field measuring equipment →0.015~0.03mm
  - After the initial installation alignment, we need to spend more time to do smooth alignment.
  - Develop new alignment technique.

5、Workload estimate

Component quantity preliminary statistics (incomplete)

Component	Collider Ring	Booster	Linac& BT	Total
Dipole	2546	16320	184	19050
Quadrupole	3524	2036	533	6093
Sextupole	1864	448	24	2336
Corrector	5808	1206	149	7163
Superconducting Cavity	240	96		456
Superconducting Cavity Assembly	40	12		72
Superconducting quadrupole	8			8
Superconducting sextupole	32			32
Septum Magnet		144		144
Kicker		22		22
Solenoid	4		37	41
Accelerating structure			285	285
Cavity			6	6
BPM	4900		240	5140
Detector	2			2
Total	21484	20284	1458	40710

- If dipoles longer than 10 meters are divided by 6 meters

Component	Collider Ring	Piece	Total
Dipole（93.4m）	4	16	64
Dipole（67m）	20	12	240
Dipole（61m）	4	11	44
Dipole（50m）	2	9	18
Dipole（45m）	16	8	128
Dipole（44.2m）	20	8	160
Dipole（34.1m）	16	6	96
Dipole（31.8m）	32	6	192
Dipole（28m）	2400	5	12000
Dipole（9.7m）	32	2	64
Total	2546	83	13006

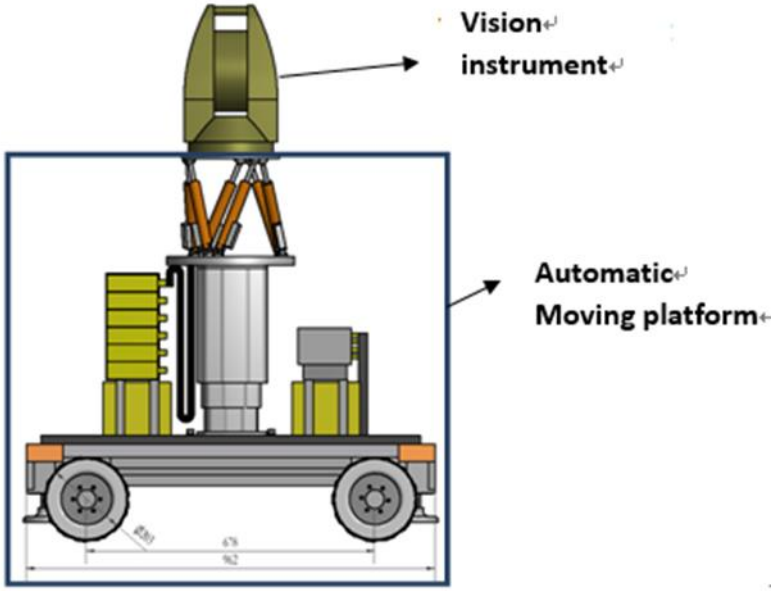
The number of components need to be aligned will be 51170

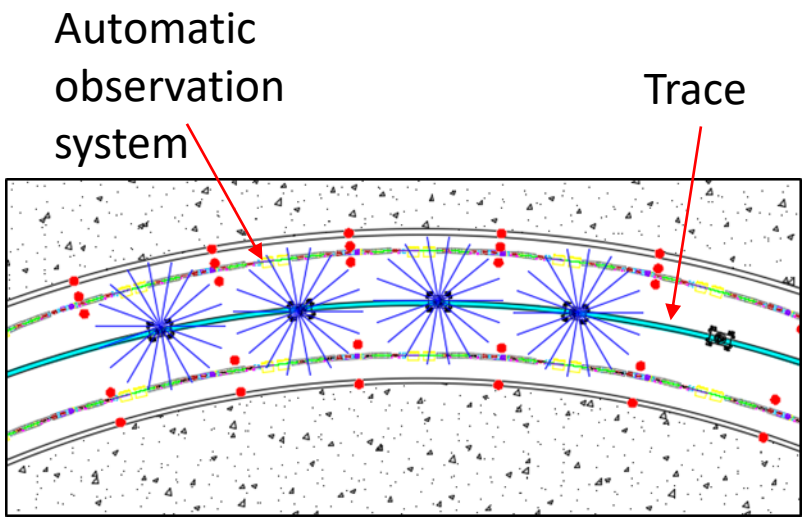
- 1 group 1 day can alignment 2 difficulty components / 4 common components.
- If 1 group 1 day alignment 3 components, it will take 1 group 17057 days to finish 51170 components alignment

- The total length of tunnel control network is about 101610m.
- 1 group 1 day can measure 4 stations+4 stations repeat measurement, the length of 4 stations is about 24m.
- It will take 1 group 4234 days to finish tunnel control network survey.
- How many time spend for alignment depends on how many groups we can have.

6、Researches

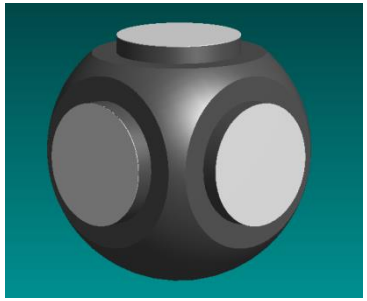
- Develop automatic observation system to improve tunnel survey efficiency
  - ➢ Integrates an automatic mobile platform and an photogrammetry instrument.
  - ➢ The automatic mobile platform can be guided by a reflective stripe on the tunnel ground and provides a suitable position for vision instrument measurement.



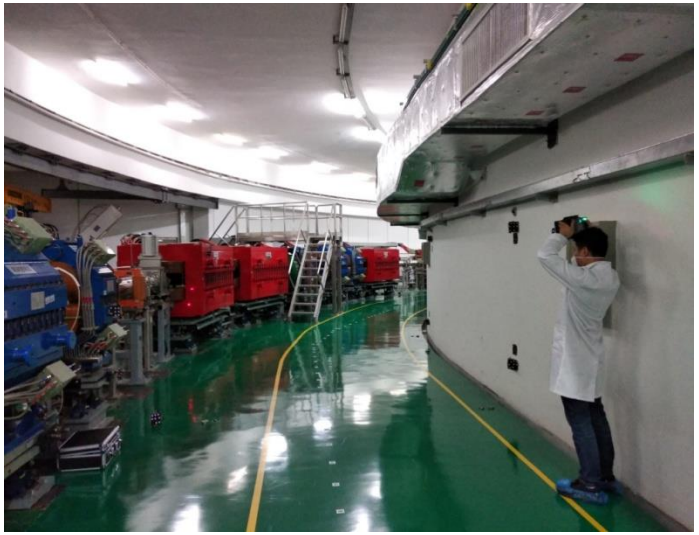


- Cooperated with a company, we have developed a 3+3μm camera.
- Designed a five faces target for photogrammetry which can be observed from different directions.
- One million capacity coded object has been developed and the recognition software has been tested.
- We have carried out 3 times measurement experiment to explore the accelerator photogrammetry survey method.
- Result shows, photogrammety is more efficient and convenient than laser tracker, but the precision still need to be improved.

3μm+3ppm Camera

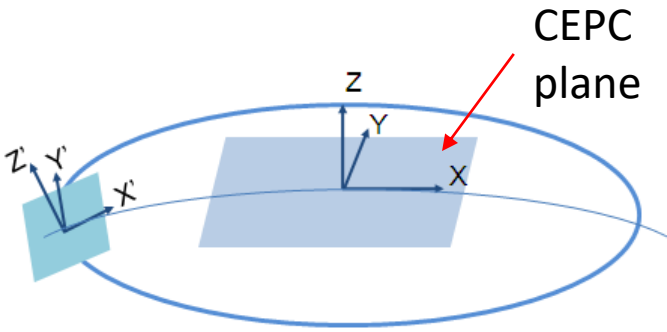


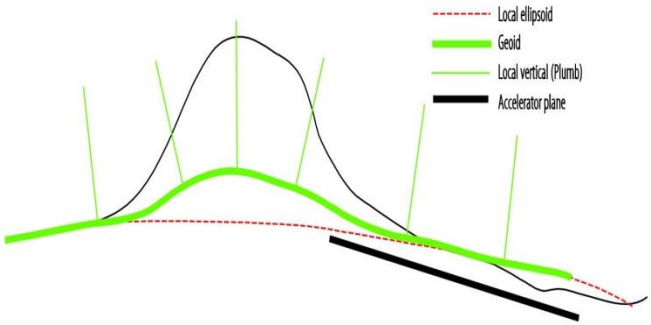
Five-face target



Photogrammetry experiment

- Geoid refining:
- Level measurement is based on the local geoid which gravity direction is not same with the CEPC global coordinate system Z axis.
- When we transfer the level measurement data to the global coordinate system the difference need to be considered.
- The geoid is an irregular surface because of earth density variance and the ground's undulation.
- We need to get a precise geoid model for CEPC alignment.
- Using gravity, GPS and level instruments measure a certain density points within CEPC area.
- Use gravitational field data to establish the grid-based geiod model .
- Further researches need to be carried out and invite experts help us to make detailed schemes.





Gravimeter

7、Summary

- Alignment strategy is introduced.
- Surface network will be measured by GPS. How to plumb accurately for long distance need further research.
- Component fiducialization is mainly carried out by laser tracker, articulate arm and photogrammetry. Detailed component fiducialization scheme will be made in future.
- Tunnel alignment is based on control network and laser tracker.
- A laser collimator system will be applied to decrease the alignment errors in interaction region.
- HLS and WPS will be used for stability monitoring.
- A preliminary workload estimate is made.
- The biggest challenges are how to increase tunnel survey efficiency and smooth alignment accuracy.
- To improve tunnel survey efficiency an automatic observation system base on photogrammetry is put forward.
- Geoid refining is essential, the detailed schemes need to be researched.

Thanks !