Mechanical Engineering for SHINE Accelerator

Lixin Yin
On behalf of SHINE team

Shanghai Institute of Applied Physics
Chinese Academy of Sciences
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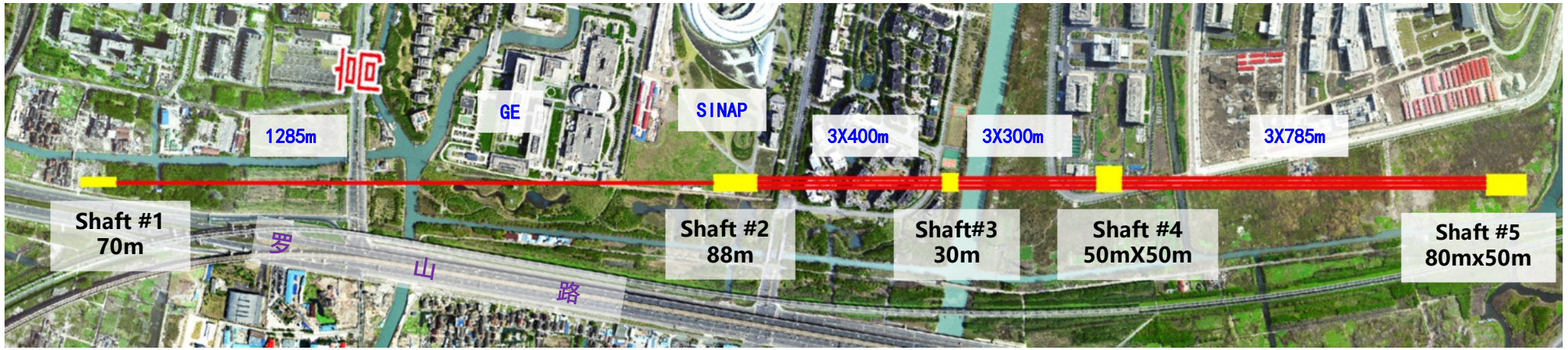
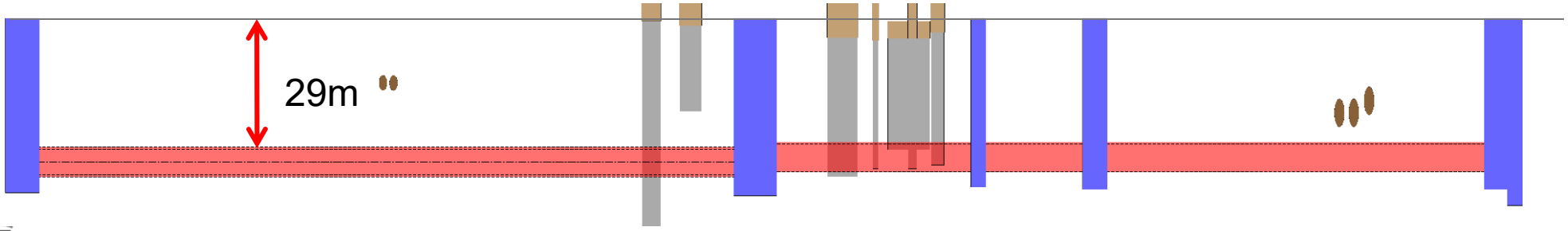
Outline

- Introduction to SHINE project
- Civil design
- Mechanical engineering
- Key components
- Summary

Scope and Layout of SHINE Project

- SHINE (Shanghai HIgh repetition rate XFEL aNd Extreme light facility)
- Approved in April 2017, ground-breaking in April 2018
- Total length 3.1km, 29m underground
- 8GeV CW Linac, 3 FEL undulator lines, 3 beamlines ,10 stations, PWs laser
- Cost: ~1.2B Euros + 0.1B Euros（R&D）
- Schedule: 7 years (2018-2025)



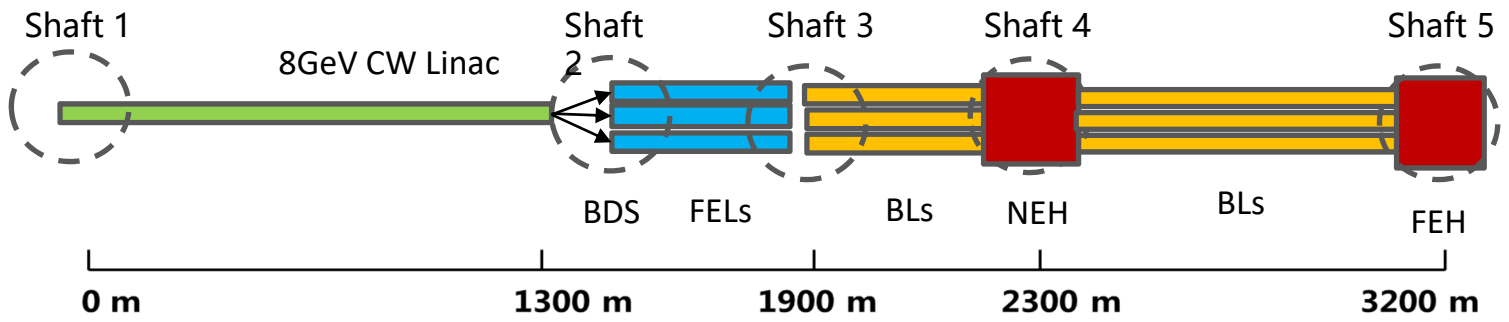


SHINE


N
S
Shanghai Hard X-ray FEL
Injector
Linac
Switchyard
SINAP
STU
Far Hall
SARI
Near Hall
Beam Dump
Undulator

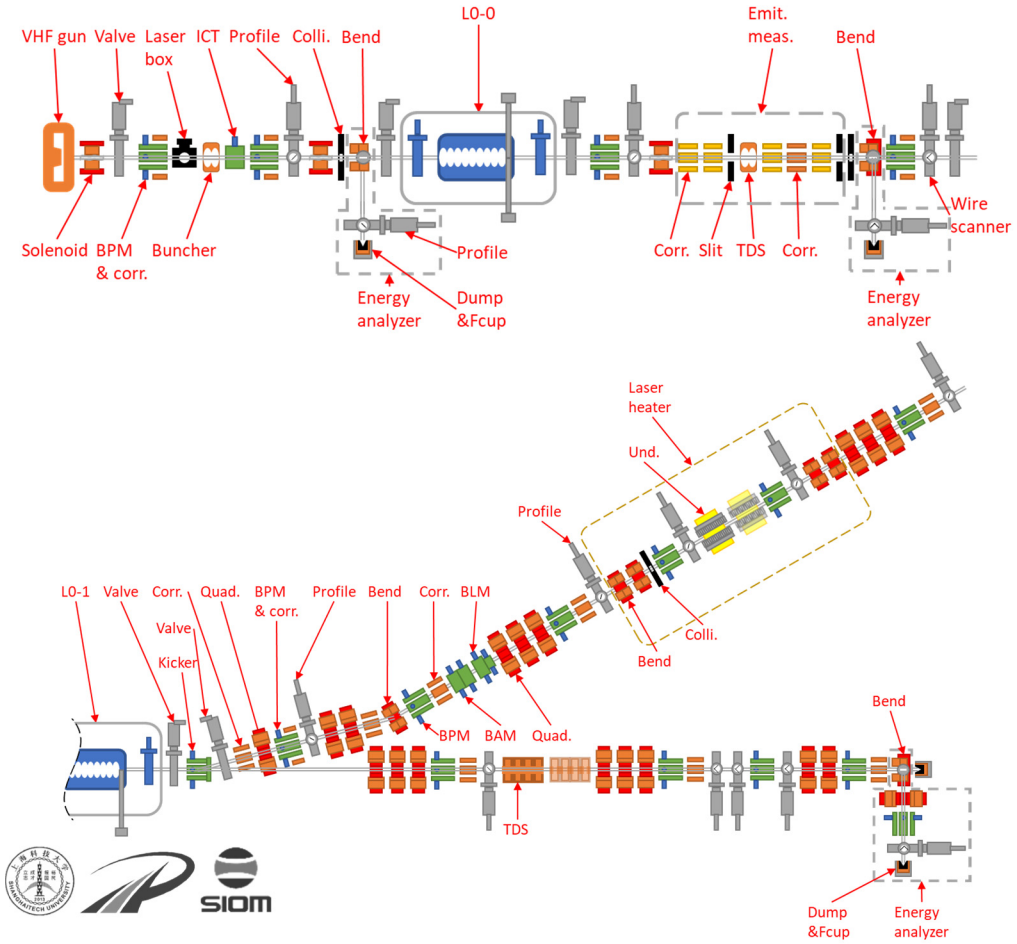
Main Parameters

Parameters	Design Goal
Electron Energy (GeV)	8
Slice Energy Spread (rms)	≤0.01%
Slice Emittance (mm·mrad, rms)	≤0.4 (0.2-0.7)
Bunch Charge (pC)	100(20-200)
Peak Current (A)	~1500 (500-3000)
Max. Rep. Rate (kHz)	1000
Photon Energy Range (keV)	0.4 - 25
Pulse Length (fs)	fs ~ 100 fs
Arrival Jitter (fs)	<30
Stability	<10%
Coherence	Transverse and temporal
Peak Power (GW)	>10 @12keV>20 @1keV



Injector

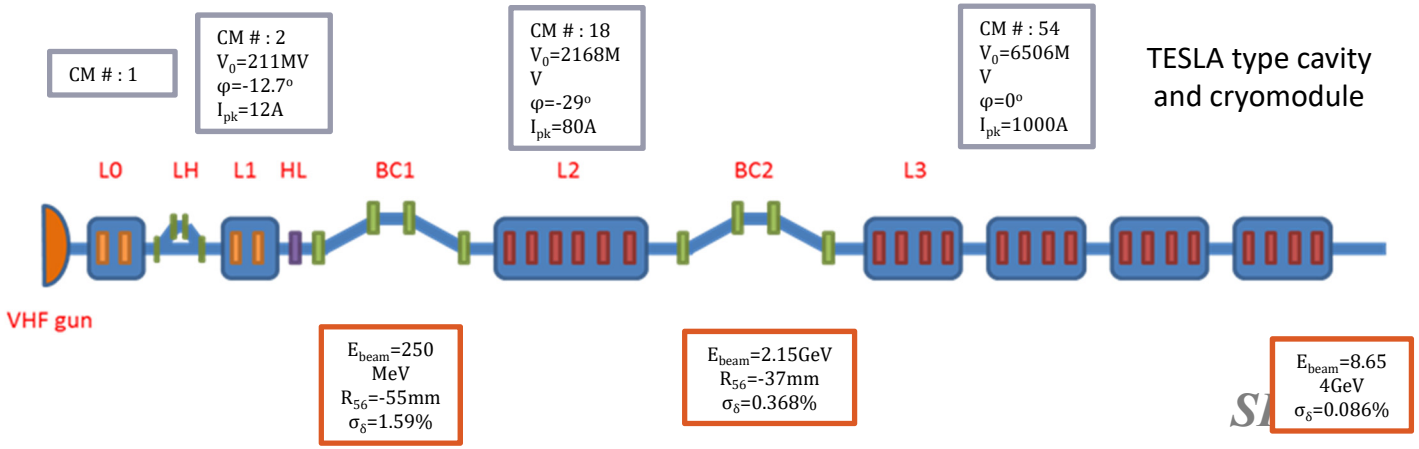
- 750kV VHF gun
- Single cavity CM
- 8-cavity CM
- DBA bending section



Linac

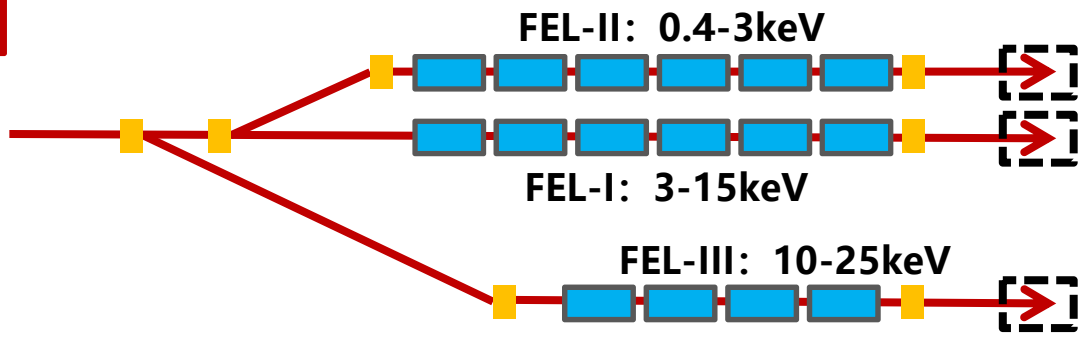
- The Linac consists of 75, 1.3GHz, 8-cavity cryomodules and 2, 3.9GHz, 8-cavity cryomodules.
- Q_0 = 2~3E10 @ E_{acc}=14~18MV/m @ 2K

	No. of CM's	Avail. Cavities	Powered Cavities	Gradient (MV/m)	E_{out} (MeV)
L0	1	8	7	16.3	100
L1	2	16	15	14.8	326
HL	2	16	15	12.5	269
BC1	-	-			269
L2	18	144	135	15.5	2148
BC2	-	-			2148
L3	54	432	406	15.5	8653
	75+2	600+16			



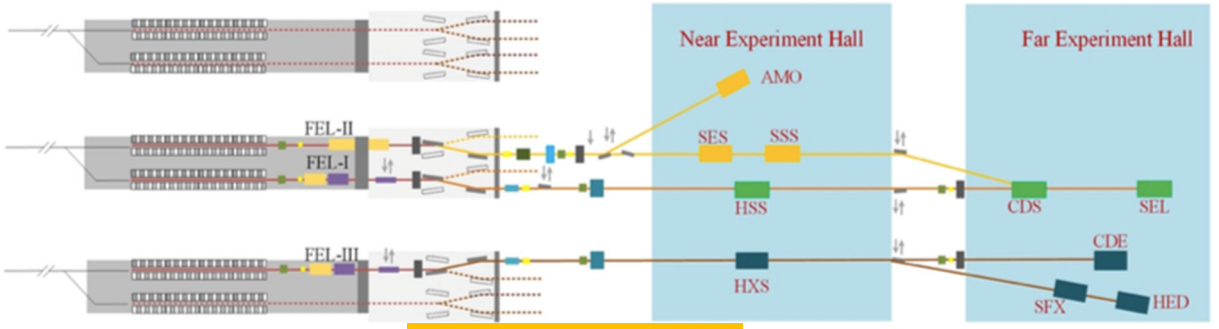
TESLA type cavity and cryomodule

FEL Lines



	FEL-I	FEL-II	FEL-III
Undulator type	Planar	Planar + EPU	SCU
Period length	26mm	68mm	16mm
Section length	5m	4m	4m
FEL modes	HXSS/SASE	SXSS/EEHG/SASE	HXSS/SASE
FEL photon energy	3.0-15keV	0.4-3.0keV	10-25keV
FEL peak power	5-25GW	30-55GW	4-18GW
FEL pulse energy*	25-1100μJ	130-2400μJ	20-800μJ
FEL BW (RMS)	0.06%	0.1%	0.027%
FEL spot (RMS)	50μm	60μm	40μm
FEL diverge. (RMS)	3μrad	10μrad	2μrad

Phase-I beamlines and experimental stations



3 beamlines **10 end-stations**

FEL-I Hard X-ray End-station

- **HSS:** Hard X-ray Scattering Spectrometer
- **CDS:** Coherent Diffraction for Single particle and biomolecules
- **SEL:** Station of Extreme Light

FEL-II Soft X-ray End-station

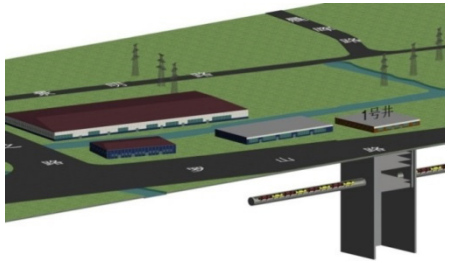
- **AMO:** Atomic, Molecular and Optical physics
- **SES:** Spectrometer for Electronic Structure
- **SSS:** Soft X-ray Scattering Spectrometer

FEL-III Hard X-ray End-station

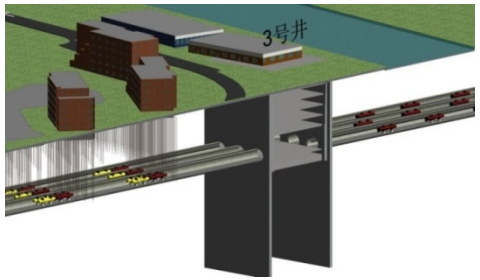
- **HXS:** Hard X-ray Spectroscopy
- **SFX:** Serial Femtosecond Crystallography
- **CDE:** Coherent Diffraction End-station
- **HED:** High Energy Density science

SHINE

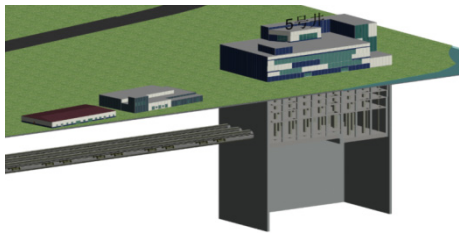
Civil Design Scheme



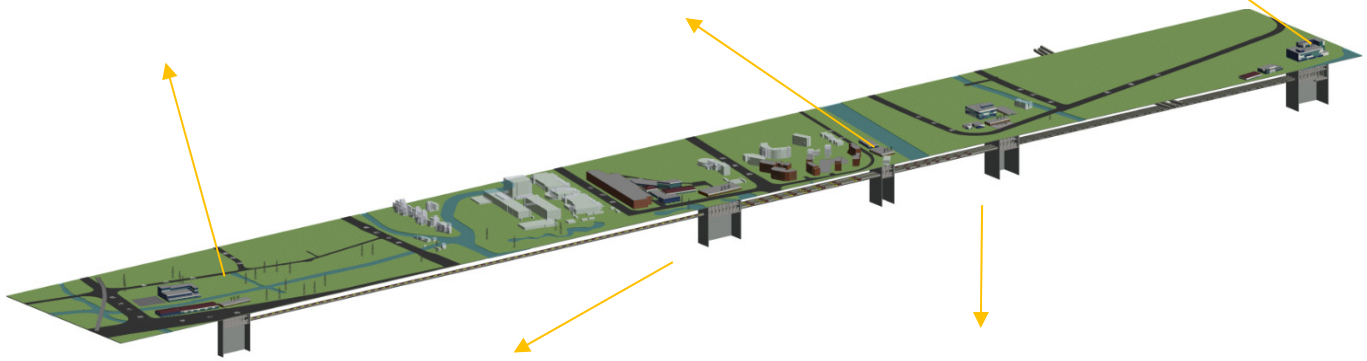
Shaft 1 Base



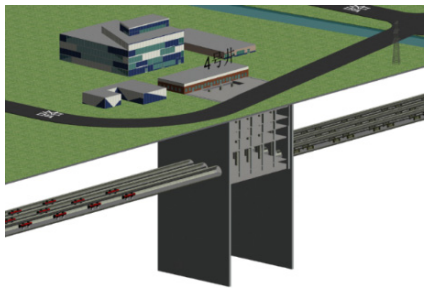
Shaft 3 Base



Shaft 5 Base

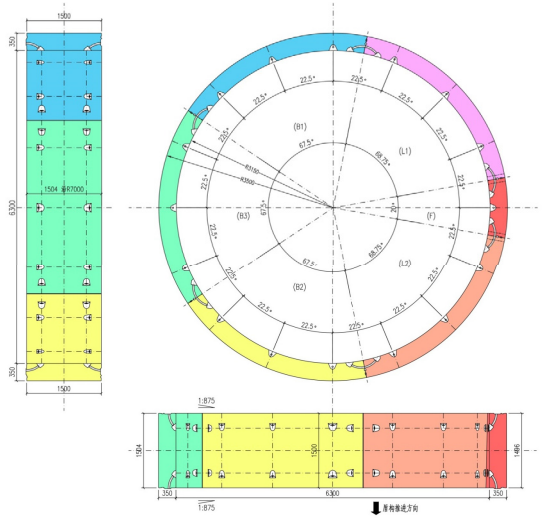


Shaft 2 Base

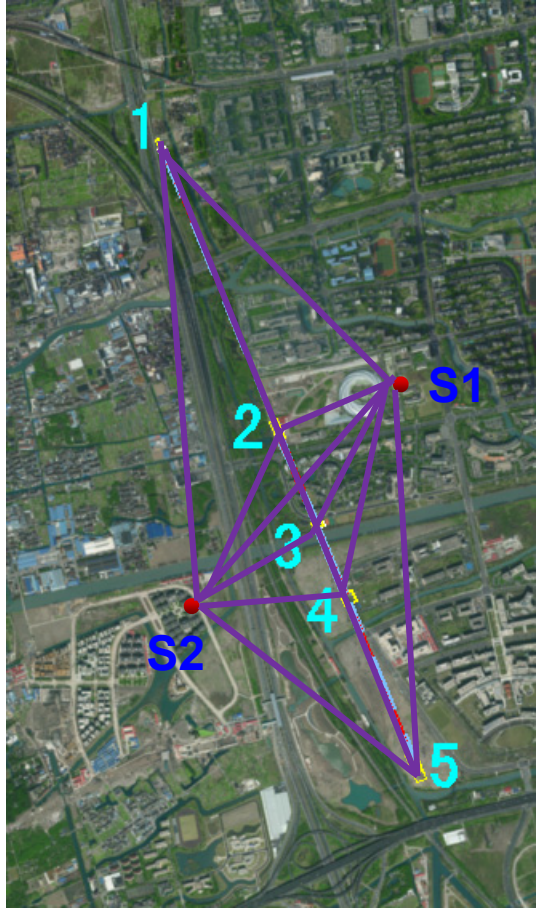


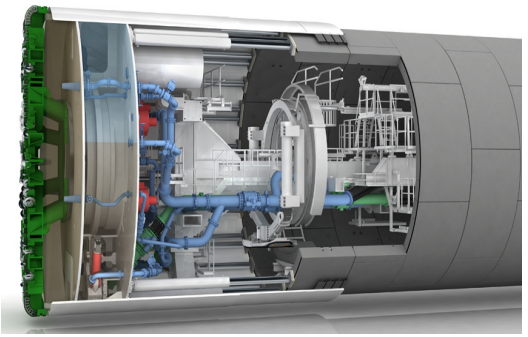
Shaft 4 Base

Structure of tunnel wall



Inner diameter of 6.3m and outer diameter of 7.0m. The segment thickness 35cm, width of 1.5m.





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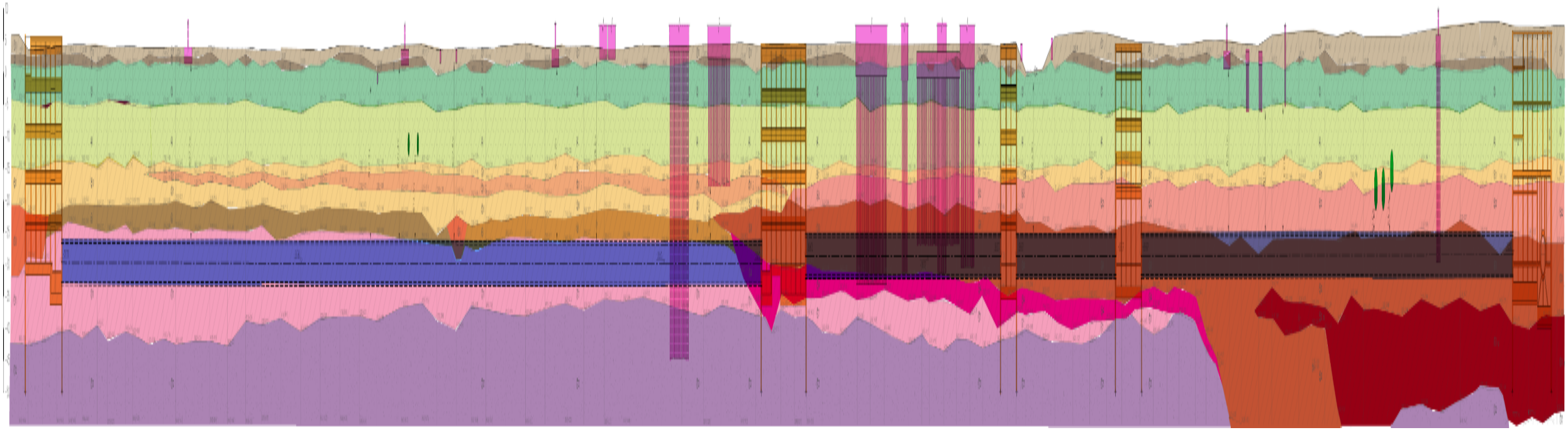
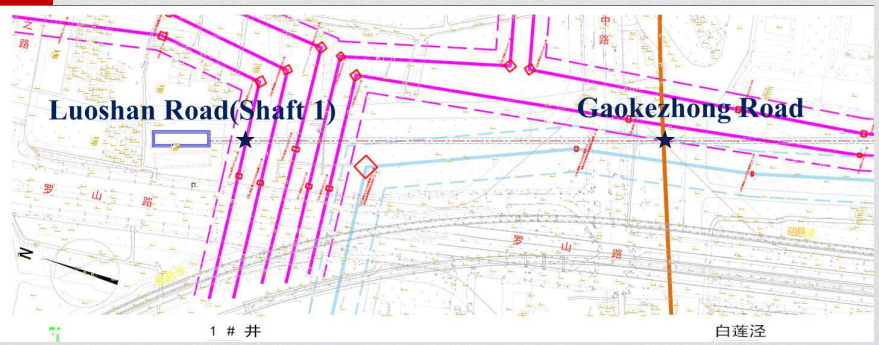
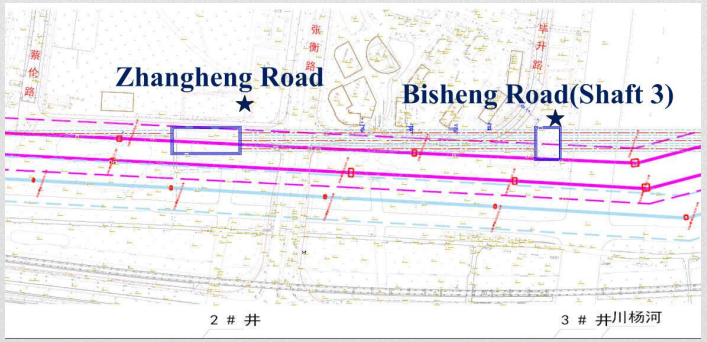
Engineering Geology Condition

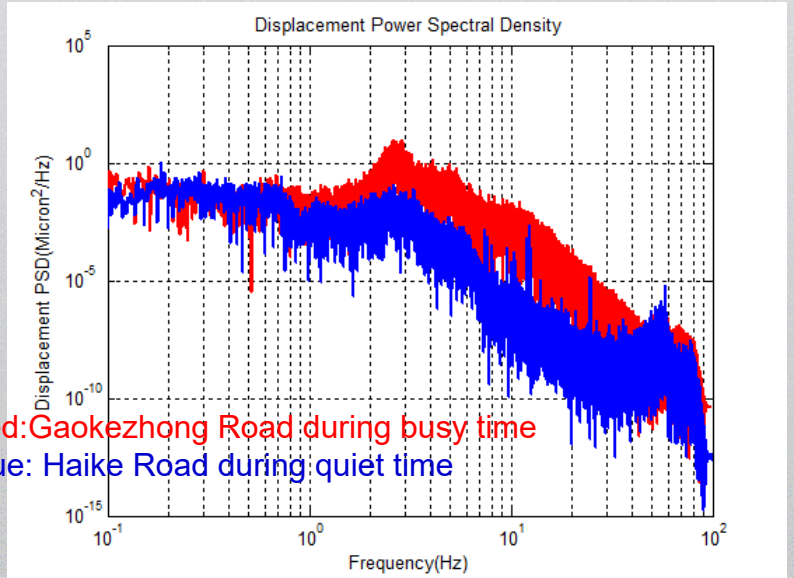
The site belongs to the coastal plain landform of Yangtze River Delta. Within the depth of 125m the ground soil is sedimentary strata. According to the genetic types, soil structure and its characteristics, there are 11 main engineering geological units.



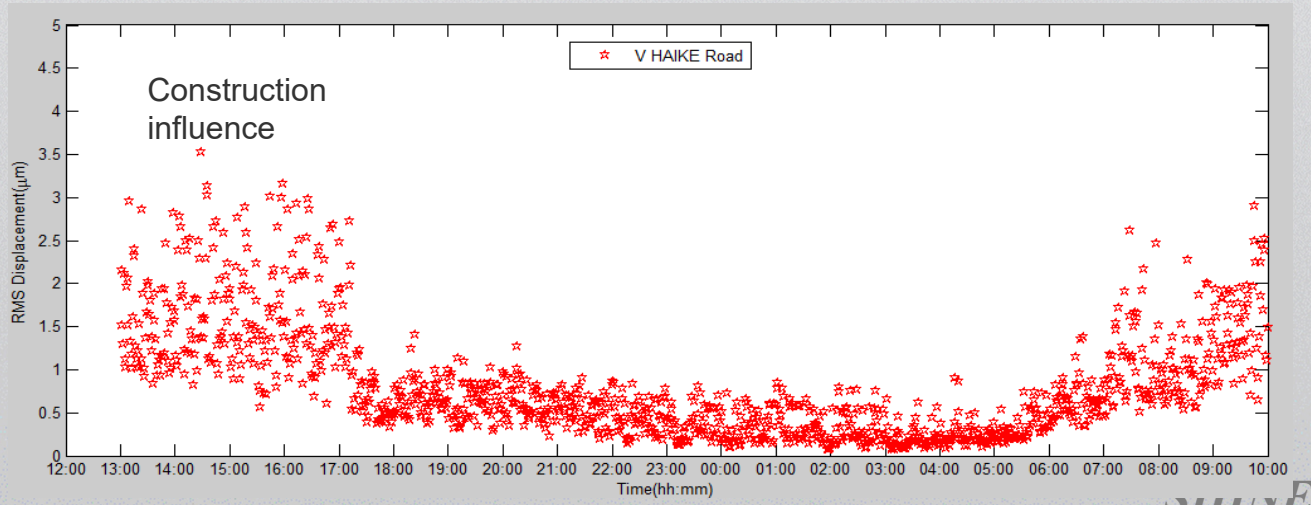
Site Vibration



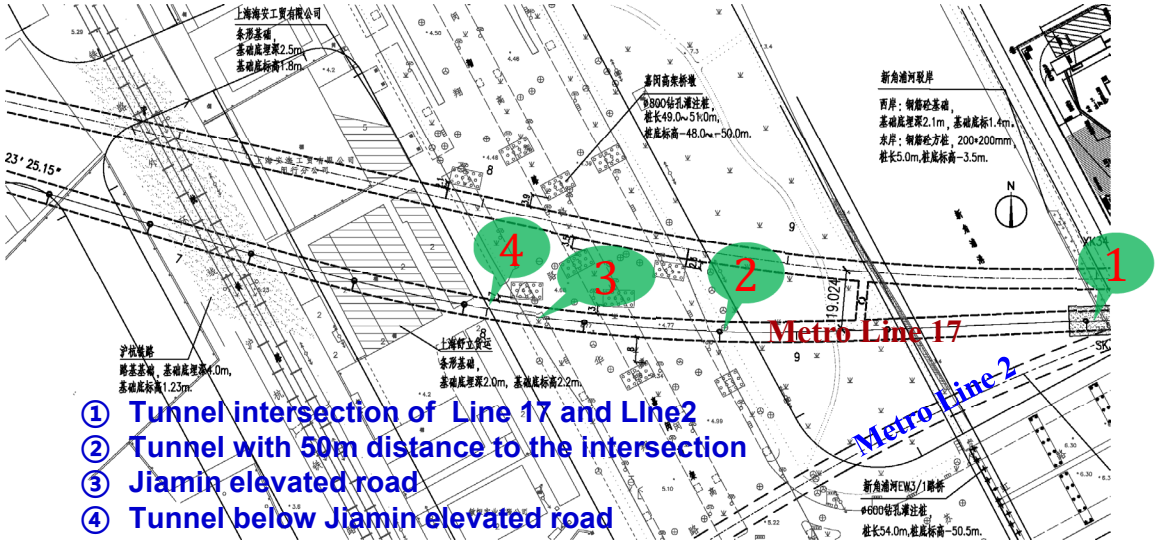


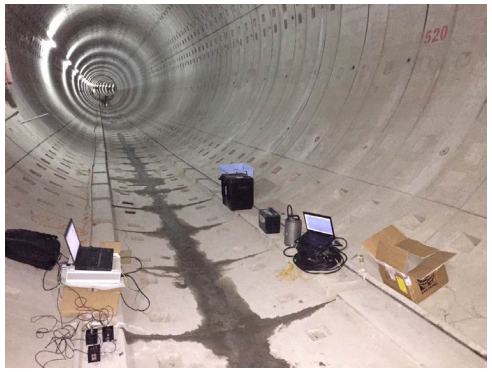


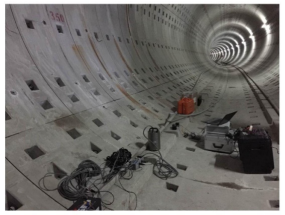
Red:Gaokezhong Road during busy time
Blue: Haike Road during quiet time



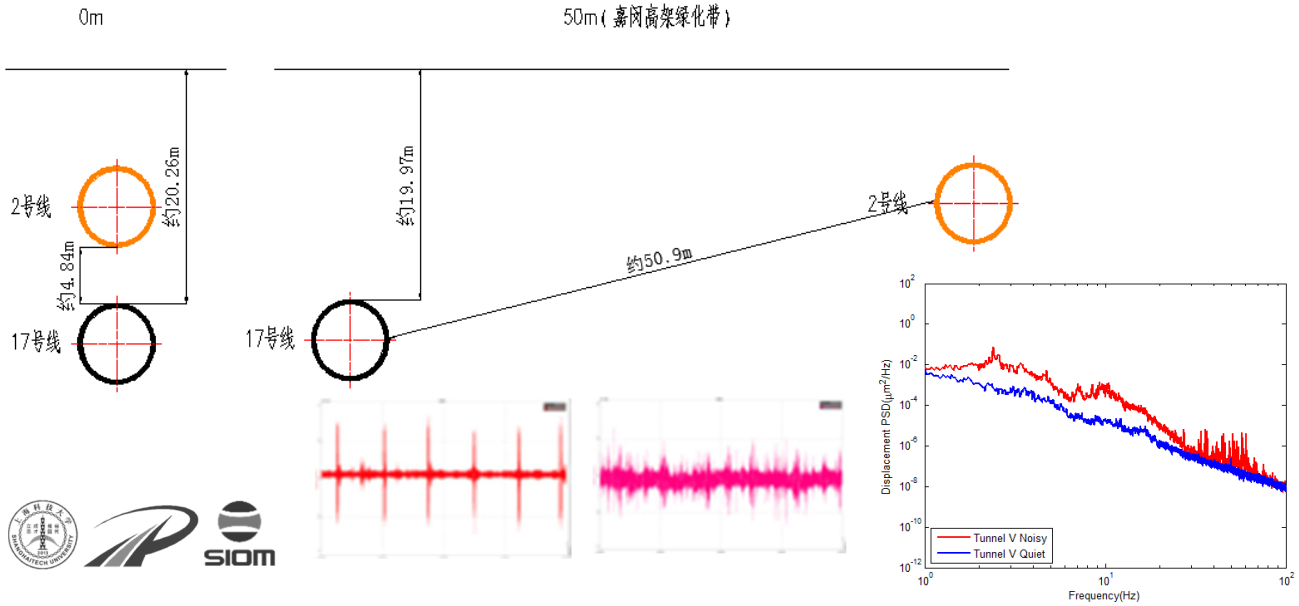
Vibration in Similar Tunnel

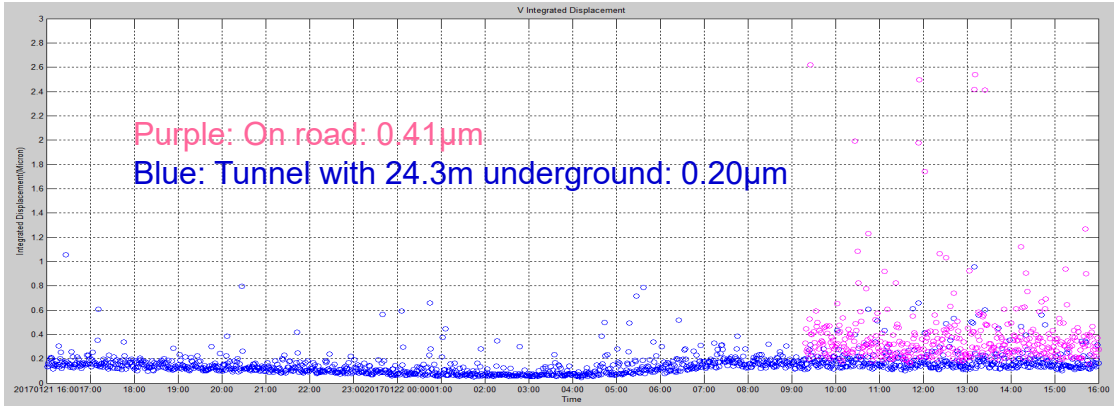




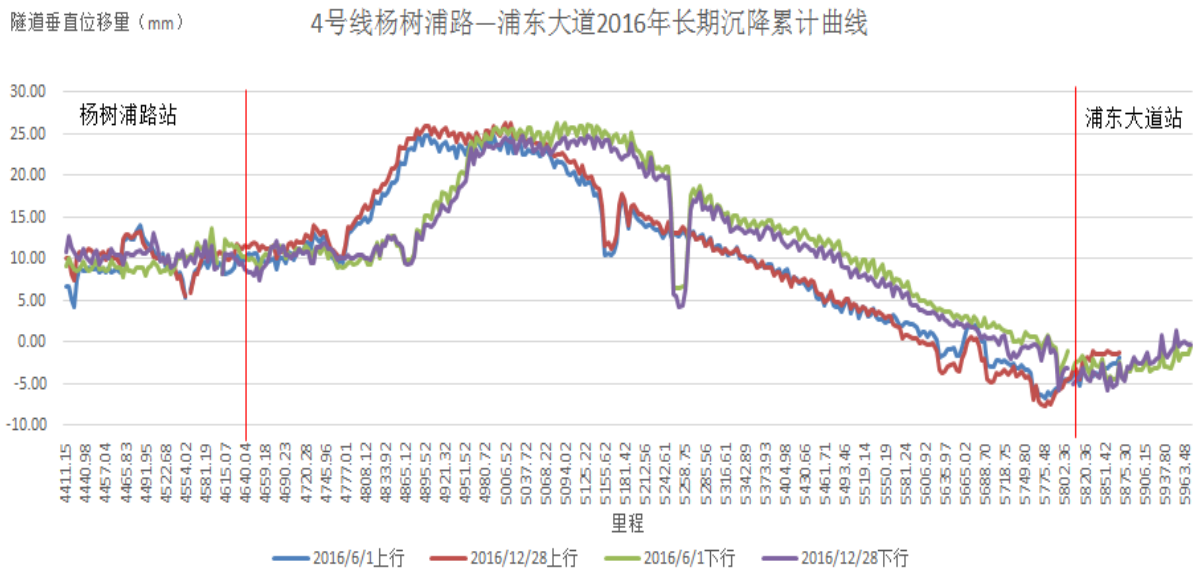


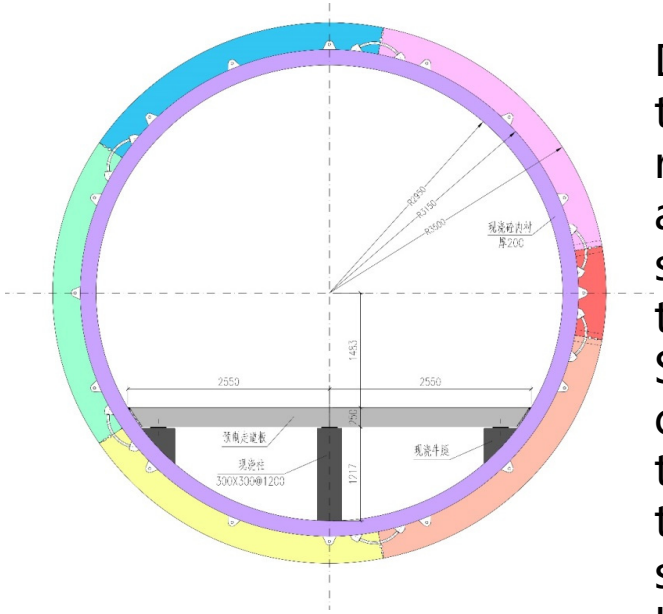
20170121		RMS(1-100Hz) (μm)		
Distance	Time	Vertical	N-S	W-E
0m	noon with metro passing	0.4378	0.5238	0.1879
	noon without metro passing	0.1767	0.1202	0.1426
	midnight	0.0754	0.0853	0.0794
50m	noon with metro passing	0.2644	0.2219	0.1510
	noon without metro passing	0.1940	0.1279	0.2015
	midnight	0.0827	0.0946	0.0825



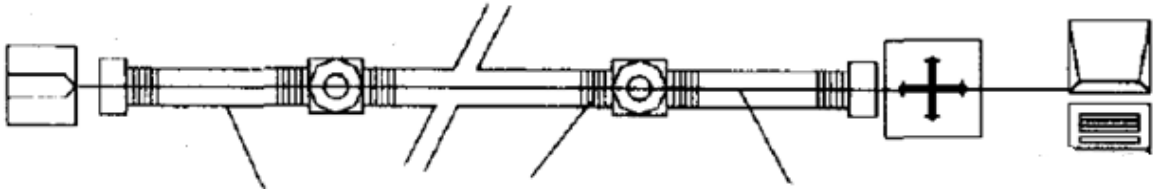


Sedimentation

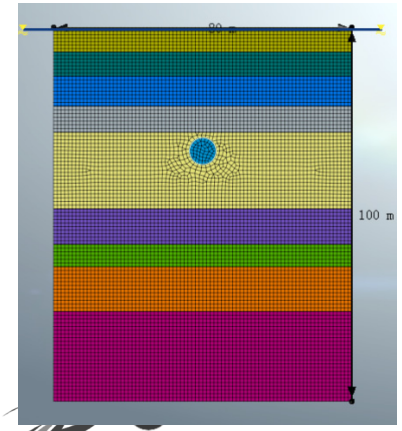


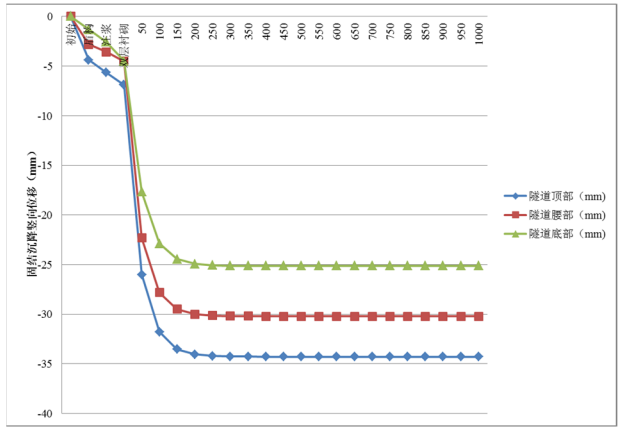


Double lining in the tunnel can effectively reduce the water leakage, and reduce the sedimentation of the tunnel.
Strictly control the construction activities in the proximity to reduce the disturbance to the surrounding soil;
Limit the ground load



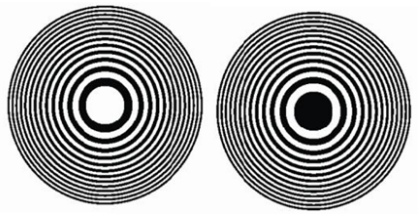
The sedimentation of the river-crossing section tunnel of Metro Lin 4 is about 25mm (2004-2016), the annual value is within 2mm.





Simulation

The results of 3D numerical analysis show that the maximum settlement at the tunnel bottom is 35mm. Considering the soil consolidation, 80% of sedimentation is in the first 3 years. And the residual sedimentation is not more than 5mm.



Zone plate
laser alignment system

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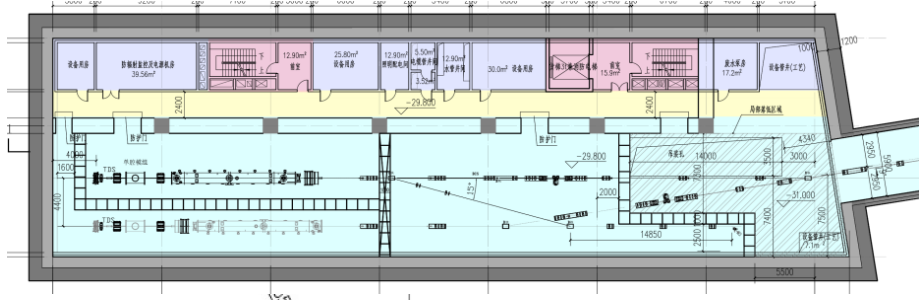
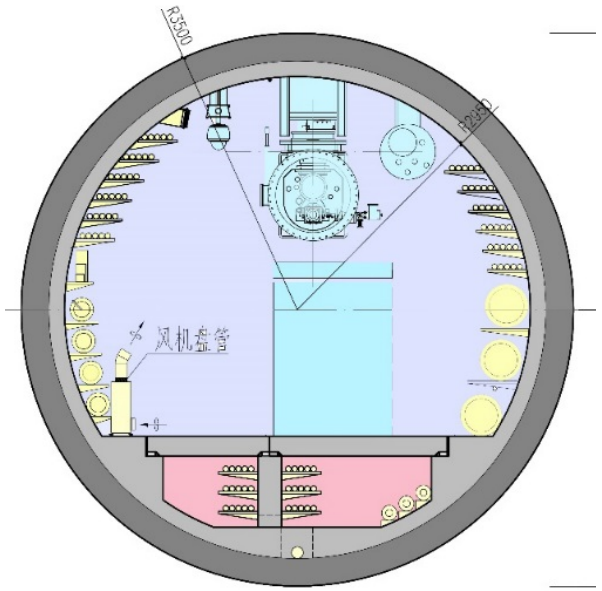
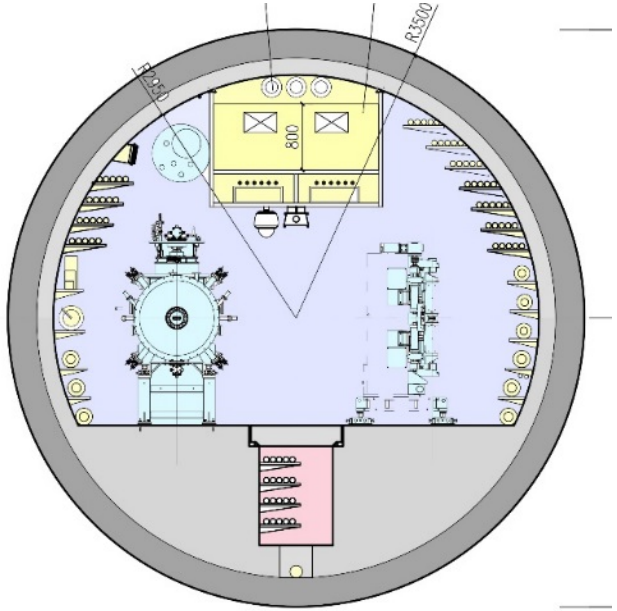
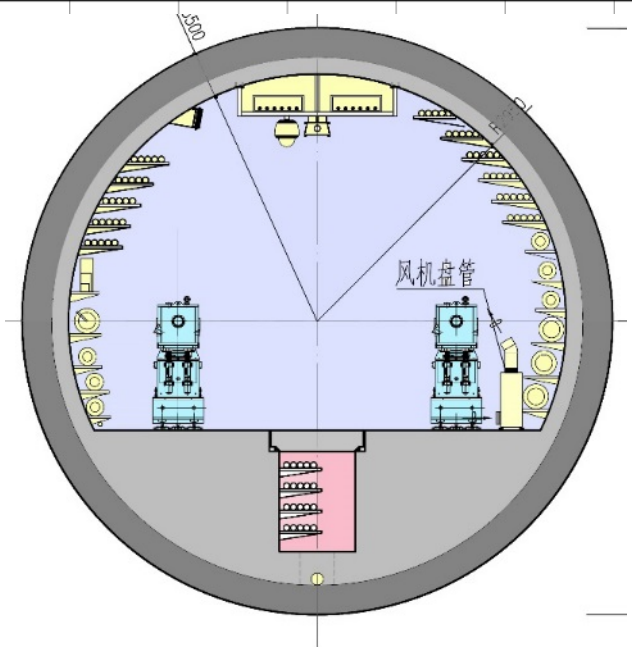
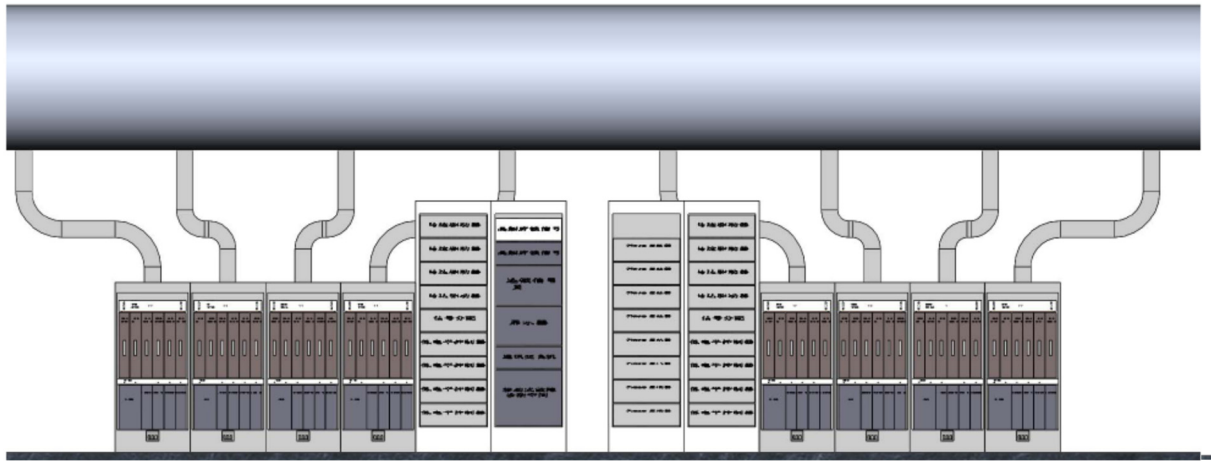
Machine in Tunnel

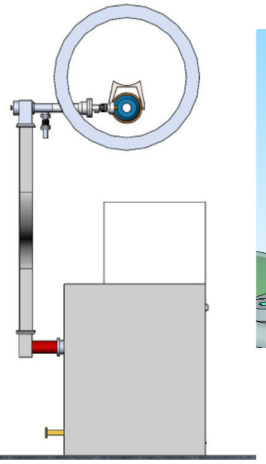


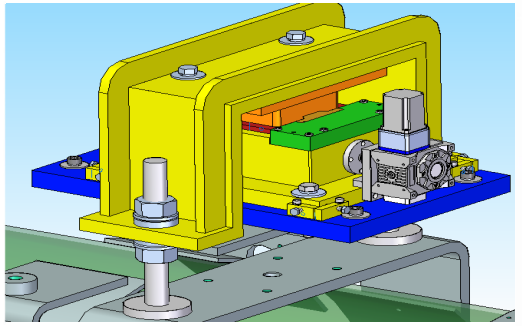


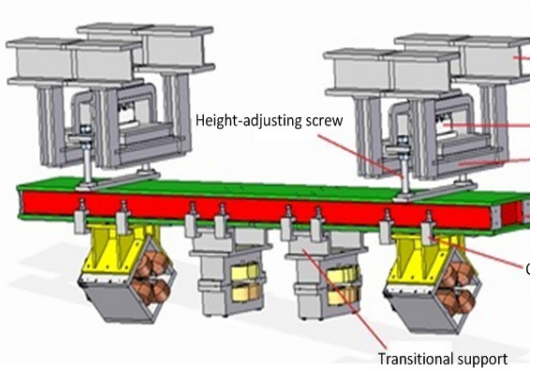












SHINE

Cryomodule

Based on TELSA technology

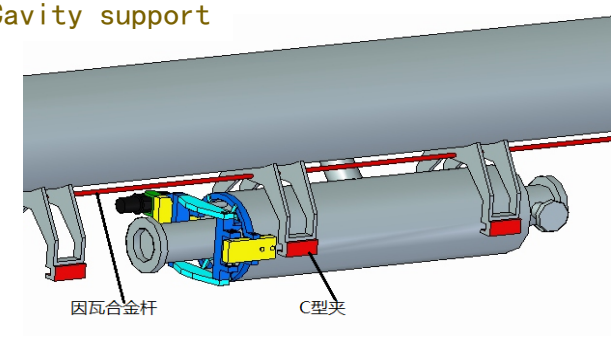
- **High technical integration of many system components and techniques**

  Superconducting, RF, magnet,

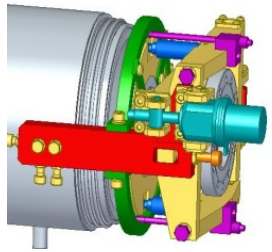
  beam instrumentation, vacuum, particle free,

  cryogenic, mechanics, alignment……

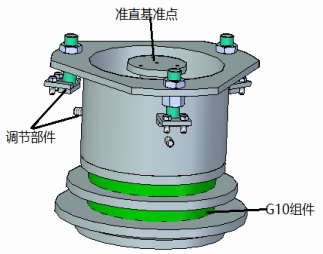
Cavity support



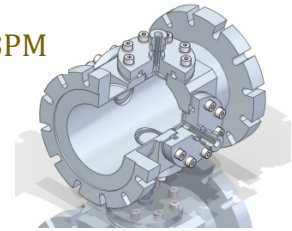
Tuner



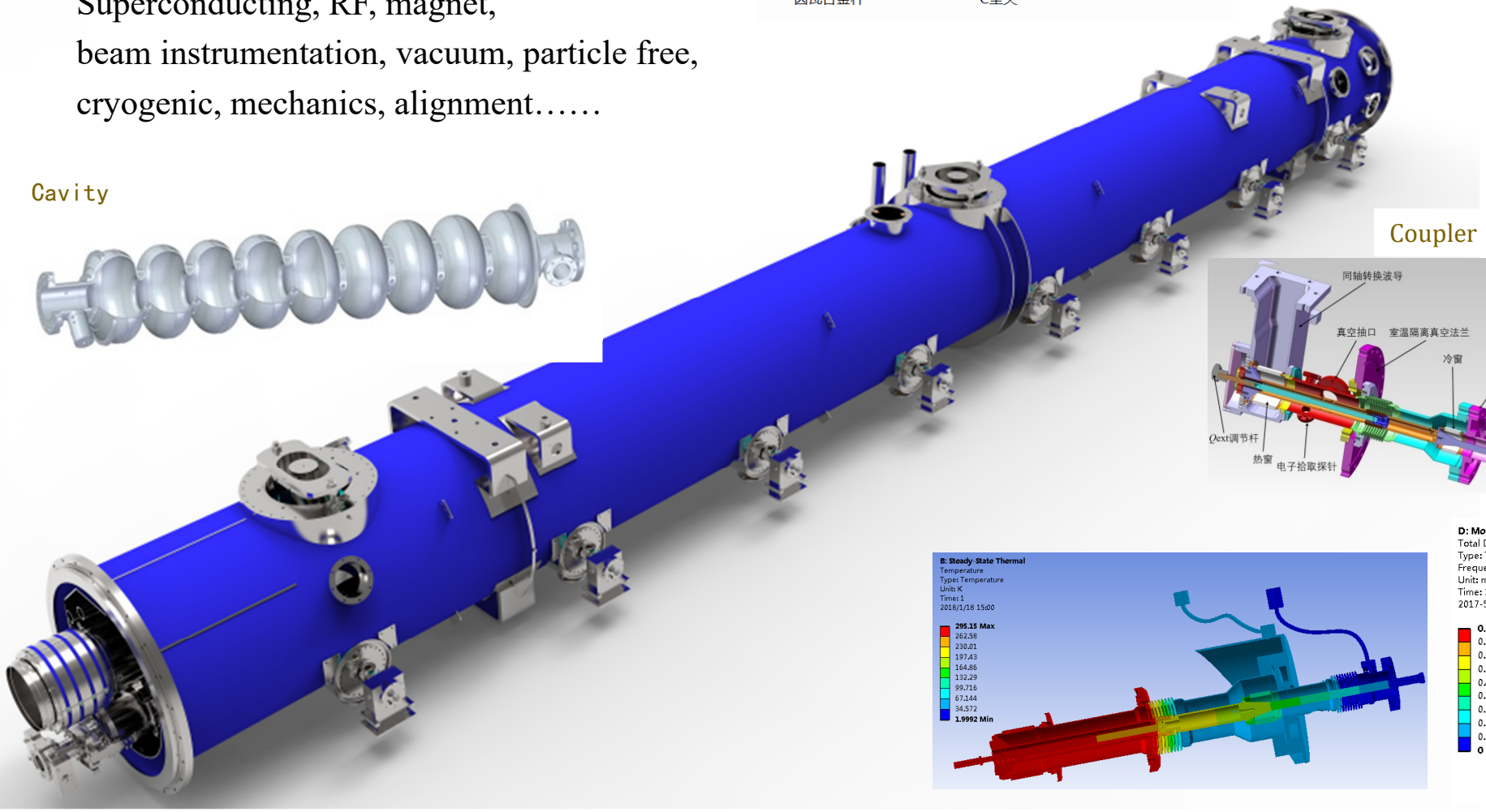
Cold mass support



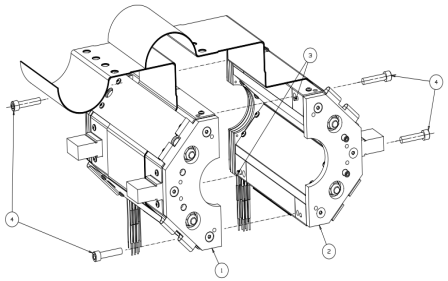
BPM



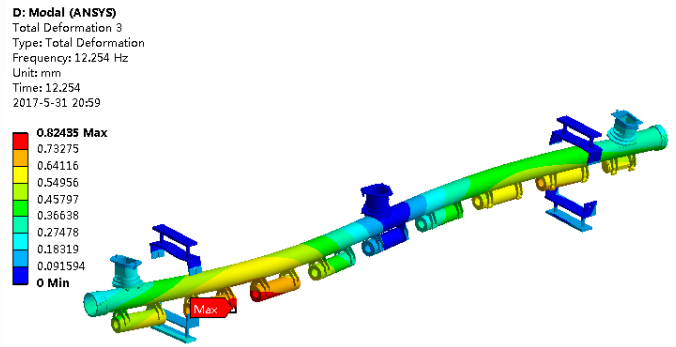
Cavity



Coupler

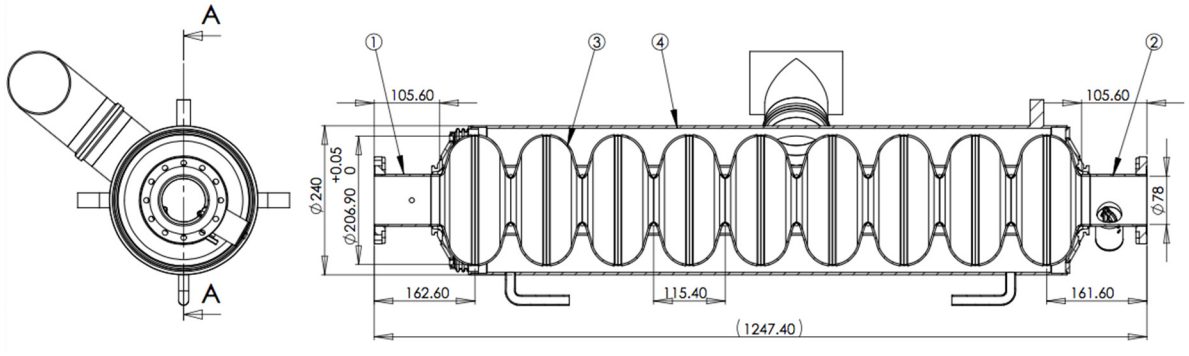


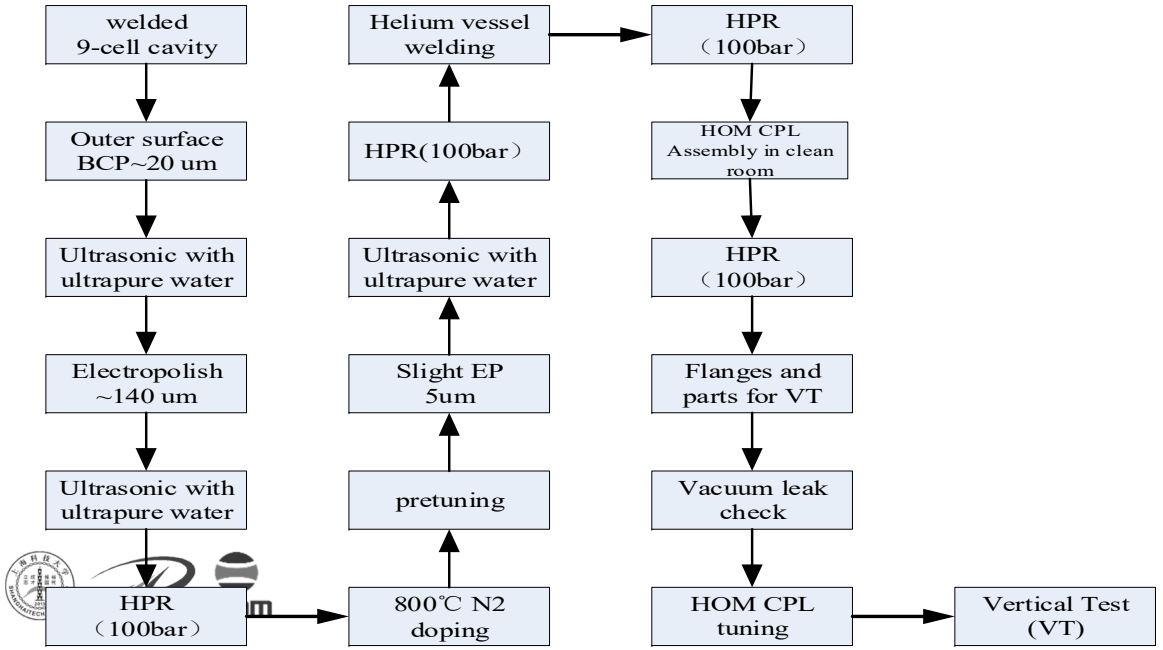
SCQ



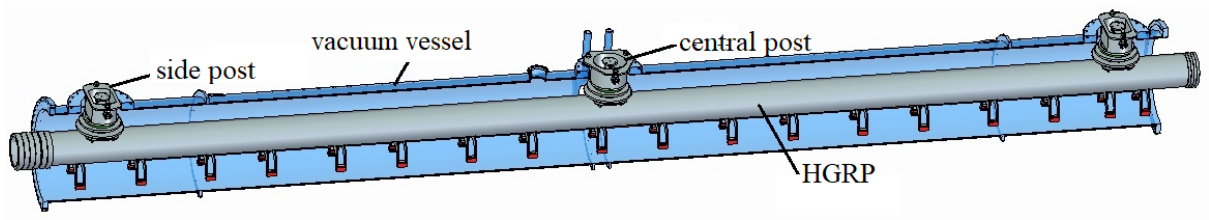
1.3GHz SRF Cavity and Support

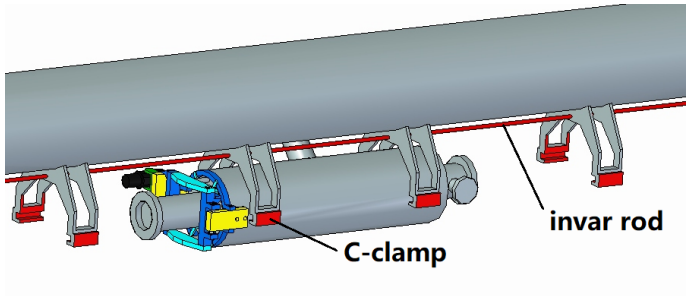
- TESLA type nine cell cavity.
- Key techniques: fabrication, surface treatment.
- High Q_0 requires low residual magnetic field.

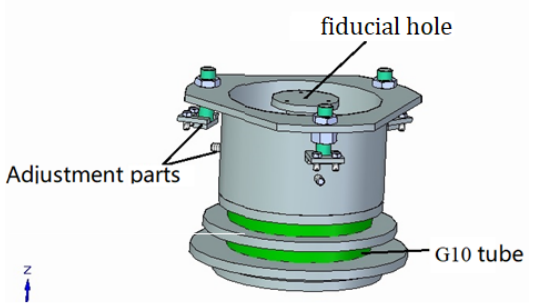




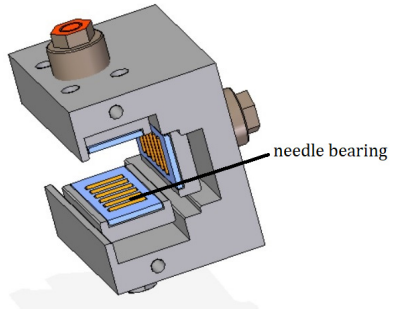
Cryomodule support







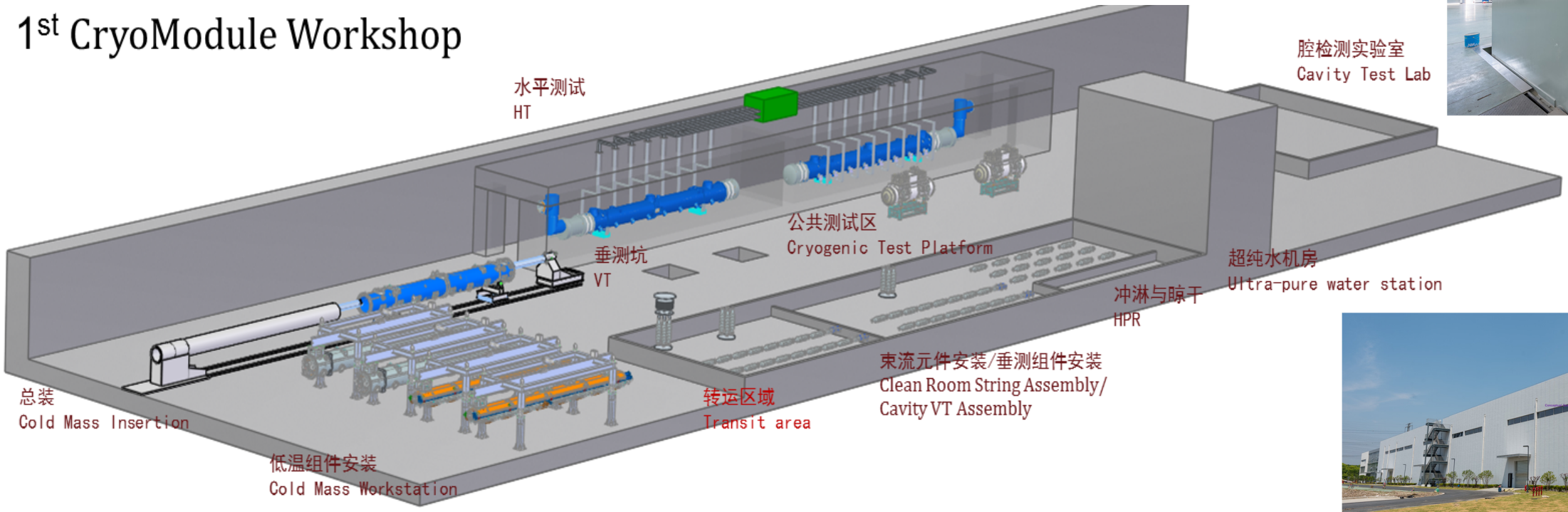
	RMS (cold)
Beam component misalignments X, Z	0.5 mm
Beam component misalignments Y	2 mm
Cavity roll misalignments	0.5 mrad
Q roll misalignments	3 mrad



SHINE

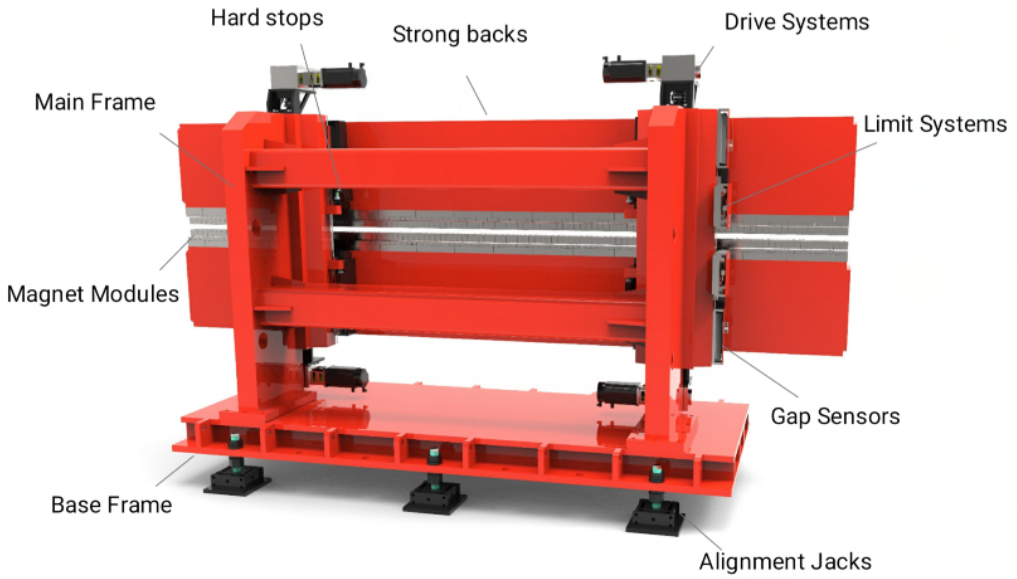
SRF Infrastructure for SHINE

- A 3000 m^2 assembly and test workshop is under constructing at SSRF campus.
- The cavity VT, cyromodule assembly and HT will be performed in the workshop.
- A 1 kW @ 2 K cryogenic system is under construction.



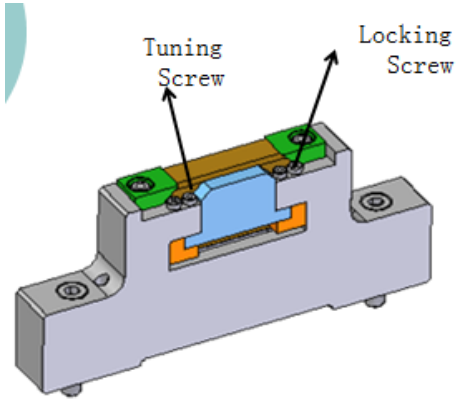
Undulators

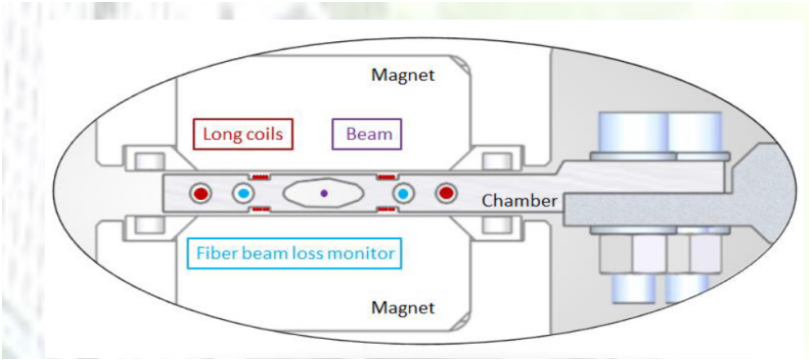
There will be 118 undulators including 74 planar undulators, 4 elliptical undulators and 40 superconducting undulators. The total effective length is about 506 meters.



U26&U68

	FEL-I	FEL-II		FEL-III
Type	Planar	Planar	Elliptical	SCU
Quantity	34	40	4	40
Period Length (mm)	26	68	68	16
Effective Length (m)	5	4	4	4
Minimum Gap (mm)	7	7	5	5
Maximum Peak Field (T)	1.0	1.5	1.5/1.5/1.06	1.583





Pole Tilt<5mrad
Pole Height <0.2mm

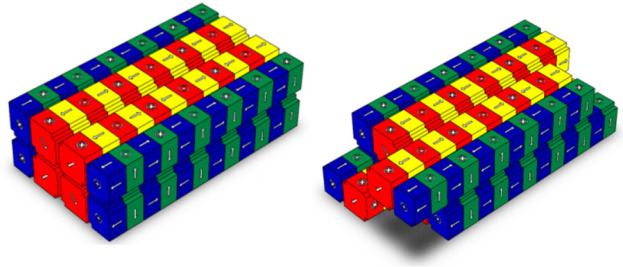
Bx：1Gs
By：1Gs

SHINE

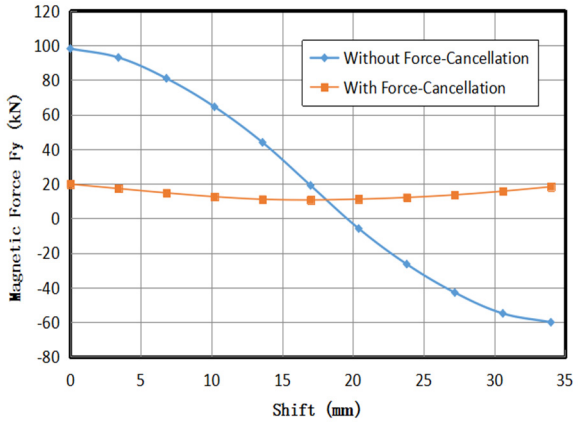
EPU68 Conceptual Design

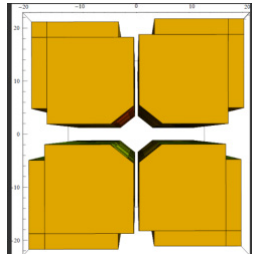
Force Compensation Design

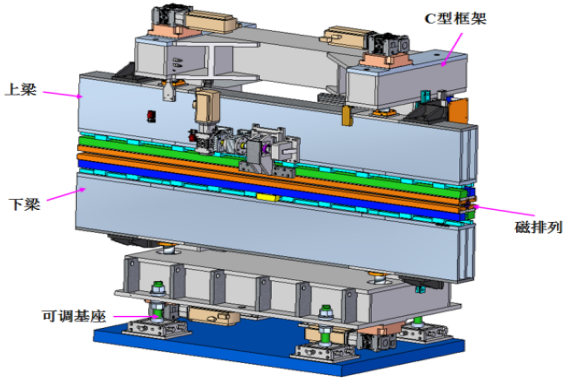
- Additional APPLE-II magnet arrays to decrease the vertical magnetic force.
- from 98 kN to 20 kN!



Magnet Structure	APPLE-III
Period Length	68 mm
Period Number	58
Effective Length	4 m
Minimum Gap	3.5 mm
Magnet Material / Remanence Br	NdFeB / 1.25 T
Magnet Block Dimension	30×30×17mm with a 3×3 mm chamfer
Bore Diameter	Φ9.2 mm
Maximum Effective Peak Fields	LP: 1.50 T C.P: 1.06 T



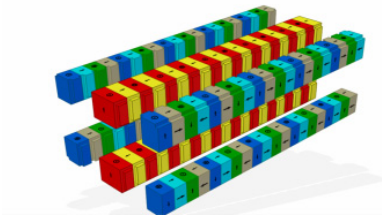


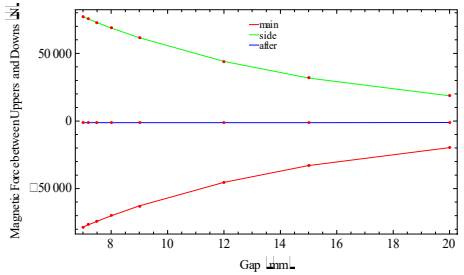


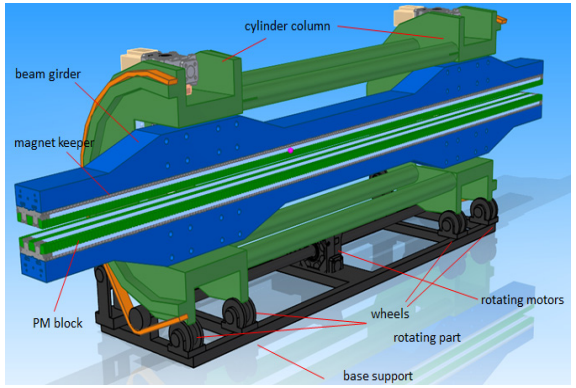
Compact Design

- PPM, magnetic force cancellation
- Linear polarization adjustable
- Compact structure : weight < 2 ton

Maximum Field	1.5 T
Minimum Gap	7.2 mm
Maximum Gap	80 mm
Beam Deformation	Less than 10μm



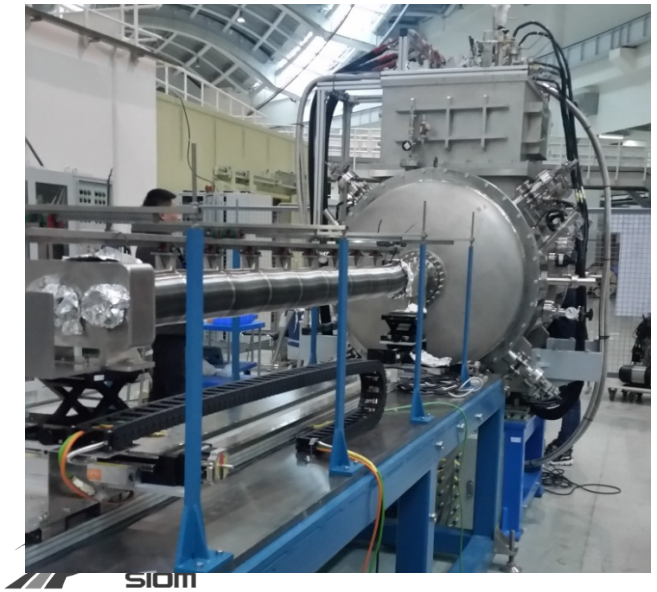




Superconducting Undulator

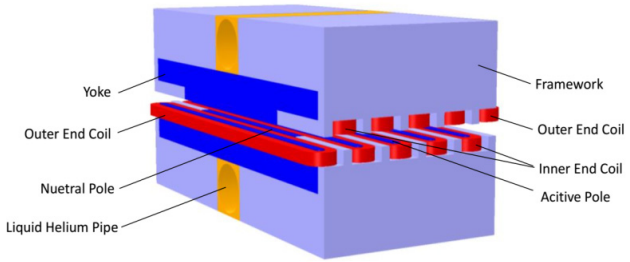
Prototype

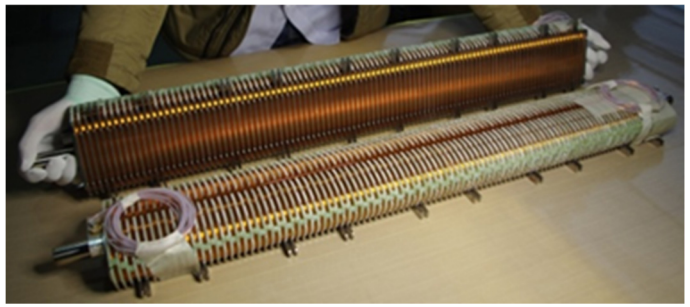
Pick field (T)	0.64
Period length (mm)	16
Period number	50
Magnetic gap (mm)	9.5
SC material	NbTi
SC wire size (mm)	Φ0.6 (with insulation)
Operation current (A)	388



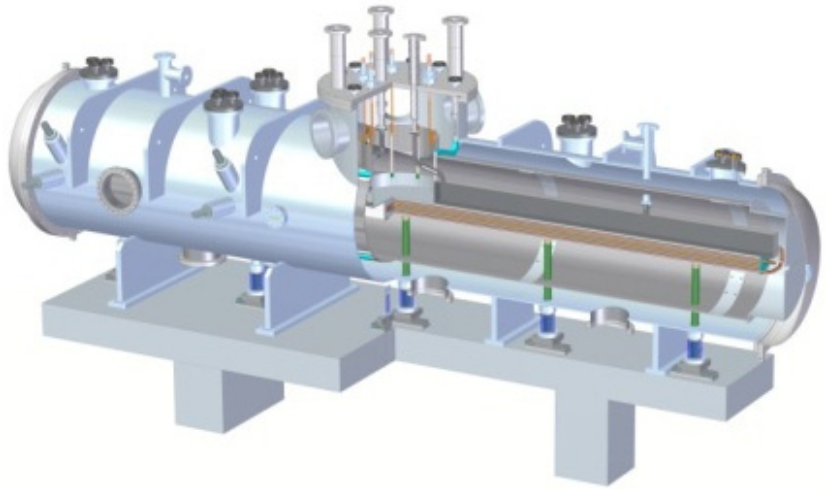
Conceptual Design

The cooling of the dynamic heat load, the magnetic field measurement and optimization of the magnetic field are the most critical techniques for SHINE superconducting undulators.





Beam Energy	8 GeV
Period Length	16 mm
Period Number	250
Effective Length	4 m
Magnetic Gap	5 mm
Core Material	Cobalt Vanadium Ferrite
Coil Type	Horizontal Racetrack
Winding	NbTi/Cu (Φ0.6)
Turns per Coil	60
Current	57-380 A
Peak Field	0.682-1.583 T
Photon Energy	10-25 keV



Summary

- A CW SRF linac based hard X-ray FEL facility project at Shanghai was started in April 2018, aiming at obtaining the first light in 2024.
- The main civil design is completed. The site stability and the tunnel sedimentation were measured and simulated, which shown a targeted monitoring and mechanical design shall be considered.
- Key components R&D, including the cryomodule and undulators, are in progress.
- In next 6 years, 75 cryomodules and 120 undulators will been fabricated, a hard work for the project and for the industries.
- Extensive cooperation is important and welcomed.

Thank you !