The 12th OCPA Accelerator School (OCPA2025)

Accelerator Facilities of the University of Science and Technology of China (USTC)

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University of Science and Technology of China (USTC)

Nakhon Ratchasima, Thailand, Aug. 2025

Outline

- Introduction of USTC and NSRL
- Hefei light source (HLS-II) at NSRL
- Project of Hefei Advanced Light Facility (HALF)
- Summary

Introduction of USTC

- USTC was established by the Chinese Academy of Sciences (CAS) in 1958.
- In 1970, USTC moved from Beijing to its current location in Hefei, the capital of Anhui Province.
- Focusing on exploring new frontiers in science and nurturing young talents with global perspectives, it serves the nation as an innovator in quality education and scientific research.




Introduction of USTC

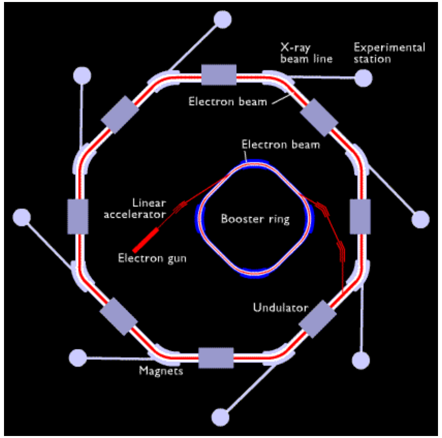
- In 1978, USTC set up the country's first “Special Class for the Gifted Young” and the first graduate school.
- USTC is also the only university that operates two national laboratories on campus: the National Synchrotron Radiation Laboratory (NSRL) and the Hefei National Laboratory for Physical Sciences at the Microscale (HFNL).
- At present, the University is home to 16245 students and 2050 faculty members, and offers customizable programs and extracurricular activities to all the students.




Synchrotron Radiation Light Source

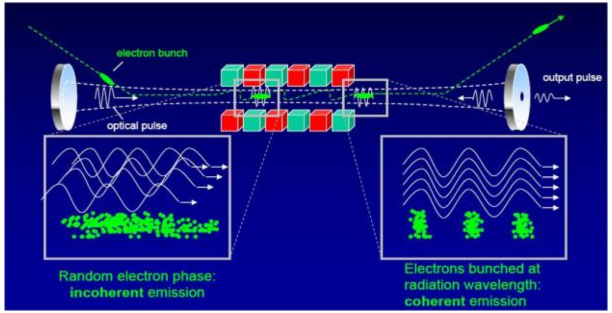
Synchrotron Radiation

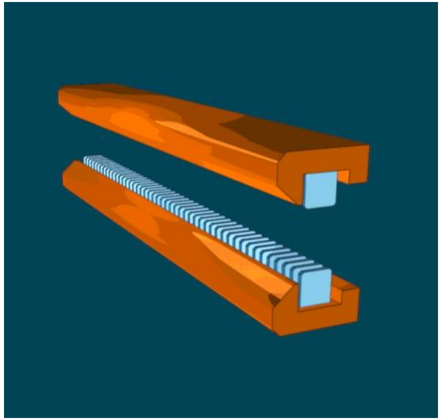
Probe to Explore the Microstructure of Materials



High quality electromagnetic radiation

- Very broad and continuous spectral range from infrared up to the hard x-ray region
- High degree of collimation of the radiation
- High degree of polarization
- Natural narrow angular collimation
- High flux
- High brightness
- Pulsed time structure
- High beam stability
- All properties quantitatively evaluable





National Synchrotron Radiation Laboratory (NSRL)

National Synchrotron Radiation Lab. (NSRL)

- The First National Lab. in China (1983)

Hefei Light Source (HLS)

- The First Dedicated Synchrotron Radiation User Facility in China (1989)

Phase I （1984-1991）

Phase II（1998-2004）

Major Upgrade（2009-2014）

Hefei Light Source（HLS-II）

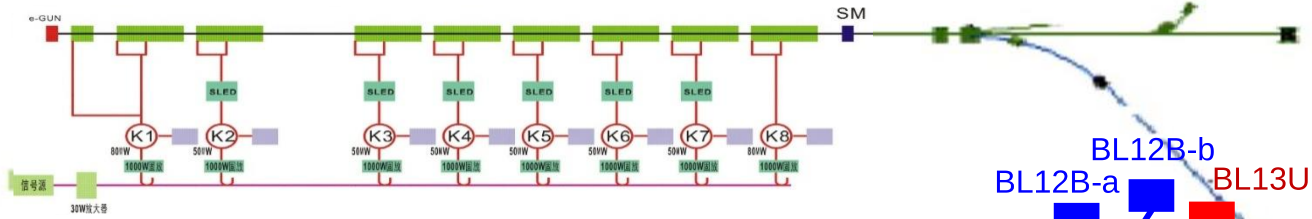
2009-2014 Full re-construction

- accelerator (Linac injector, Storage ring)
- 5 beamlines and experimental-stations

2016-2018 Upgrading

- power supply system upgrade
- performance improvement of beamlines and end-stations
- 10 beamlines
- top-off operation mode（July,2018）

Hefei Light Source（HLS-II）

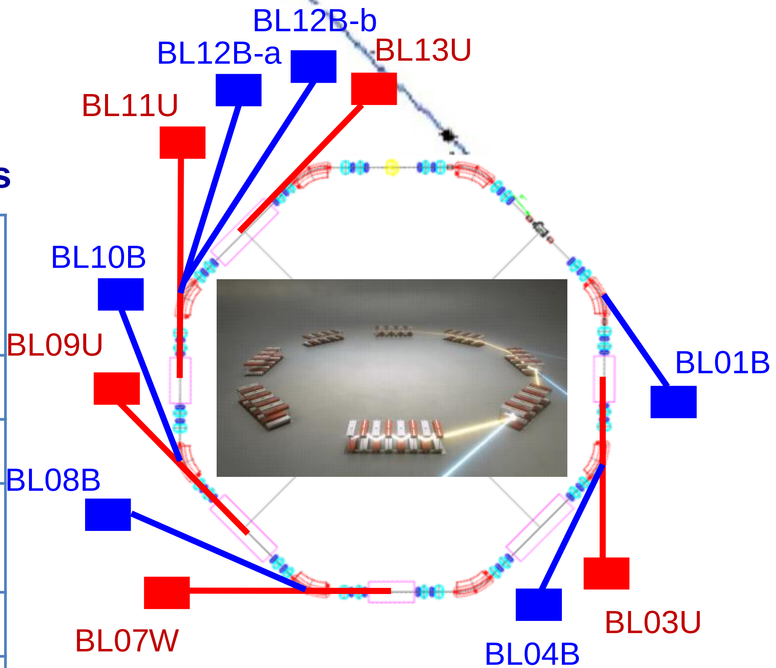


Undulator、Wiggler end-stations

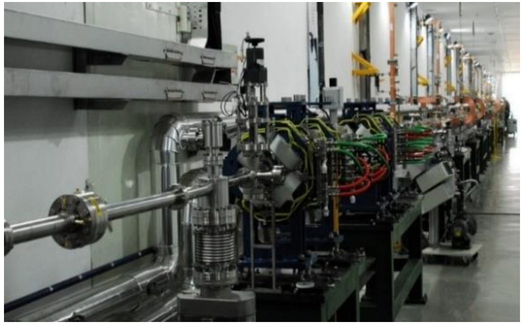
BL03U	Combustion and Flame
BL07W	Soft X-ray microscopy
BL09U	Atomic & molecular Physics
BL11U	Catalysis and Surfac Science
BL13U	ARPES

Bending Magnet end-stations

BL01B	Infrared spectroscopy and micro-spectroscopy
BL04B	Mass spectrometry
BL08B	Metrology
BL10B	Photoemission spectroscopy
BL12B-a	MCD
BL12B-b	SX-MCD



Hefei Light Source（HLS-II）



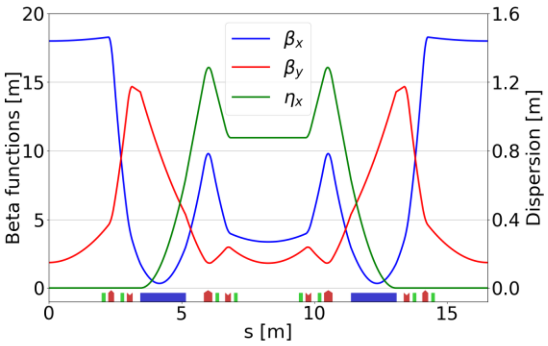
Full Energy Linac Injector in the Tunnel

Main Parameters of the Full-energy Linac

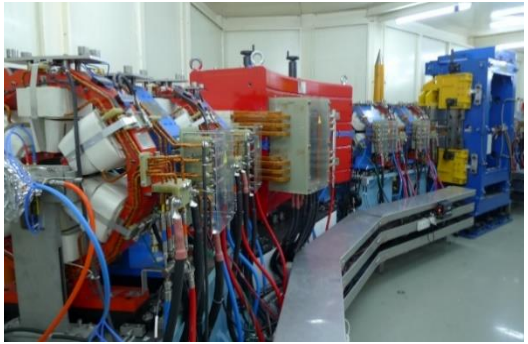
Energy	800 MeV
Microwave frequency	2856 MHz
Bunch charge	1 nC
Vertical emittance	< 60 π mm· rad
Horizontal emittance	< 60 π mm· rad
Repetition rate	1 Hz
Energy spread (rms)	0.5%

- The linac mainly consists of an electron gun and 9 acceleration sections.
- The gun is a traditional DC one with a thermal cathode. The outgoing electron beam has a macro pulse length of 1 ns and bunch charge of about 2 nC.
- After going through a pre-buncher and buncher, the electron beam bunch length turns into 10 ps.
- Each acceleration section includes two 3-meter S-band accelerating tubes which work with the traveling-wave mode. After traversing the accelerating structures, the electron beam is accelerated to 800 MeV.
- A switch magnet is installed at the end of the linac. Using this magnet, the electron beam can be delivered to either the energy spectrum analysis system, or the transport line for the injection of the storage ring.

Hefei Light Source（HLS-II）



Optics Functions of One Super Period of the Ring



Magnet Components of the Ring

Main Parameters of the Storage Ring

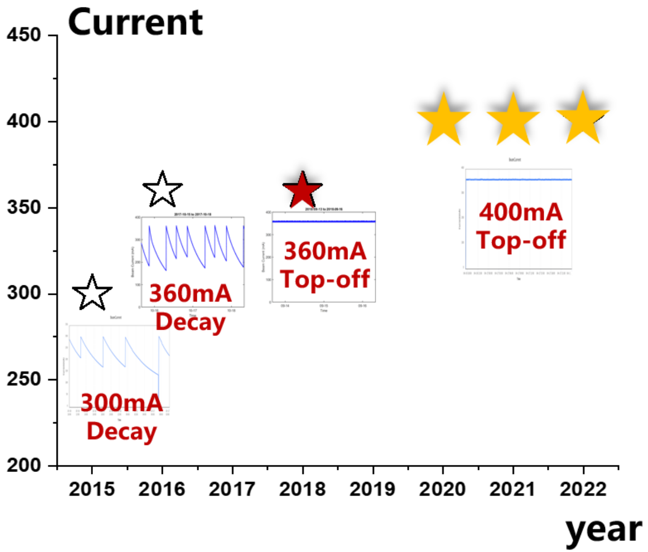
Beam energy	800 MeV
Circumference	66.13 m
Harmonic number	45
RF frequency	204 MHz
Beam emittance	38 nm· rad
Cells	4, DBA Lattice with 2 straight sections per cell (4.0 m+ 2.3 m)
Transverse tunes (H, V)	(4.44, 2.35)
Orbit stability	2 µm

- After the upgrade project, the lattice of the HLS-II storage ring was changed from TBA to DBA type to reduce its emittance to 38 nm·rad and increase the number of straight sections to 8 while remaining the same circumference.
- The storage ring is comprised of 8 bending magnets, 32 quadrupoles and 32 sextupoles with multi-functions (skew quadrupoles and orbit correctors).
- Two straight sections are used for the installation of the RF cavities and for beam injection system, respectively.
- The other straights are installed with six insertion devices, including two elliptically polarizing undulators (EPU), a quasi-period undulator (QPU), an In-vacuum Undulator (IVU), a planar undulator and a wiggler.

Hefei Light Source（HLS-II）

Operation of Light Sources in 2024

- 400mA Top-off operation
- Beam Current stability：±1%
- Availability: 99.46%
- Running time per year: 7117.39 h
- Duration of experiments: ~ 177.25 h



- 11 end stations, focusing on the research of quantum materials, catalytic science, bioscience, etc.
- More than 1000 users every year
- More than 400 user publications every year

Hefei Advanced Light Facility (HALF) Project

With development of science and technology, synchrotron radiation users put forward higher requirements for the quality of light sources

- Spatial and temporal resolution
- Experiment completion efficiency
- Stability of light source
- Operation for more users
- …

⇩

Higher flux，higher brightness，higher coherence，more insertion devices，advanced technologies in particle accelerator field,…

⇩

The fourth generation light source based on diffraction limited storage ring

Flux，Brightness and Coherence

$$Flux = \frac{N_{ph}}{\Delta T \cdot \Delta\omega/\omega}, \quad Brightness = \frac{Flux}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}, \quad f = \frac{\lambda^2/(4\pi)^2}{\Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$

$$\Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \sigma_{ph}^2}, \quad \Sigma'_{x,y} = \sqrt{\sigma'^2_{x,y} + \sigma'^2_{ph}}$$

$$\sigma_x = \sqrt{\varepsilon_x . \beta_x + \sigma_E^2 . \eta_x^2}, \quad \sigma'_x = \sqrt{\varepsilon_x . \gamma_x + \sigma_E^2 . \eta'^2_x}, \quad \sigma_y = \sqrt{\varepsilon_y . \beta_y}, \quad \sigma'_y = \sqrt{\varepsilon_y . \gamma_y}$$

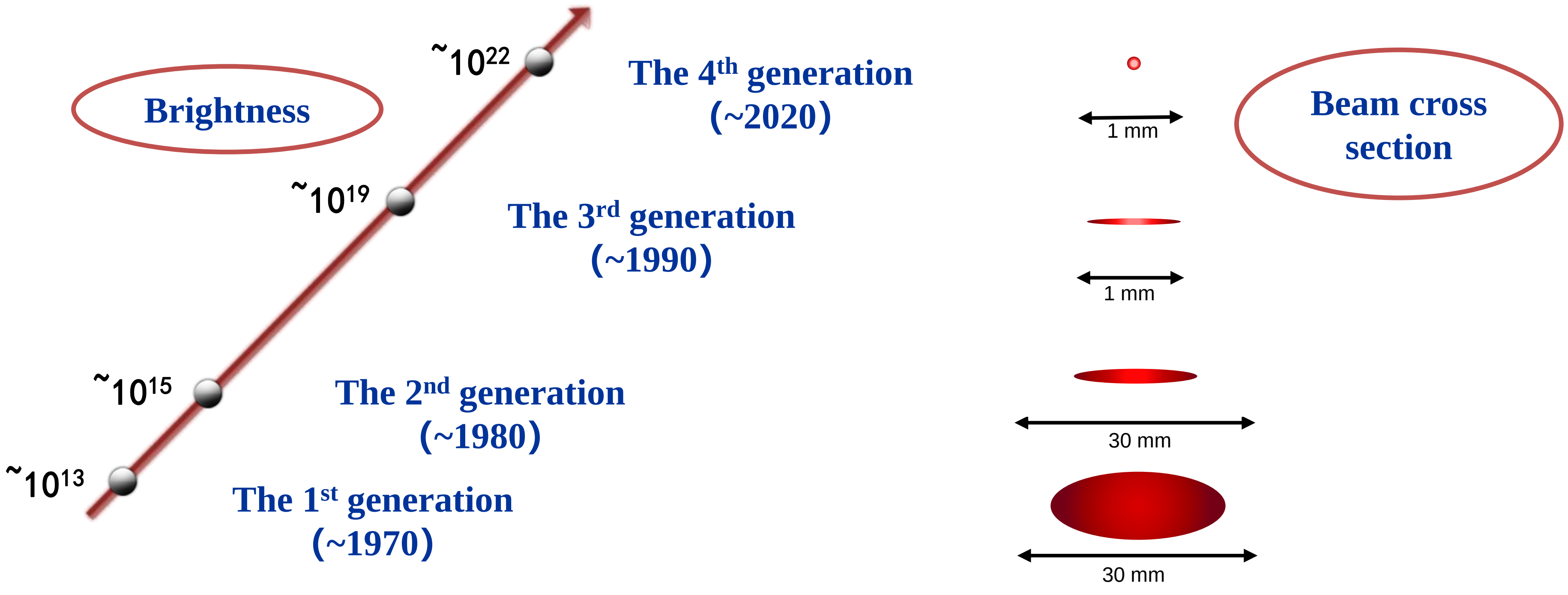
$$\sigma_{ph} = \frac{1}{2\pi}\sqrt{\lambda \cdot L}, \quad \sigma'_{ph} = \sqrt{\frac{\lambda}{4L}}$$

※ Before reaching the diffraction limit, brightness and coherence of the light source increase significantly with the decrease of beam emittance.

Diffraction limited emittance $\varepsilon_{e^-} \leq \varepsilon_{ph} = \sigma_{ph}\sigma'_{ph} = \frac{\lambda}{4\pi}$

Hefei Advanced Light Facility (HALF) Project

Brightness and coherence of the fourth generation light source are 100-1000 times higher than those of the third generation.

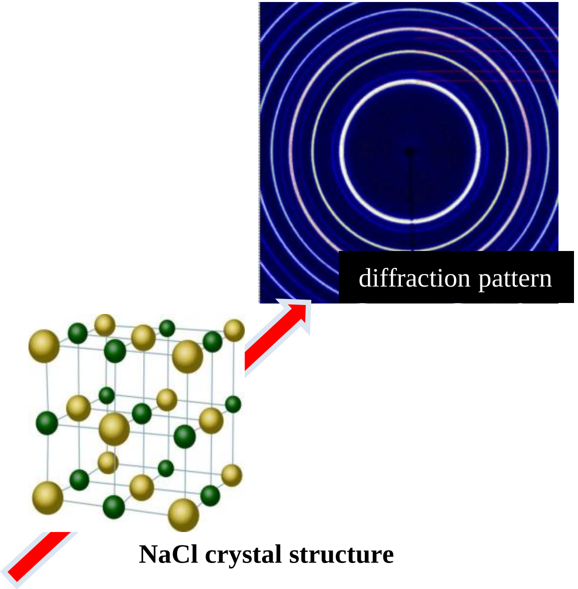


Light Sources in Different Energy Regions Address Different Scientific Questions

Hard X-Ray

Structure: Where are the atoms located? How does the atomic structure change?

In-situ observation of complex single crystal growth. Micro scale protein structure. Structural defects in high-temperature alloys …

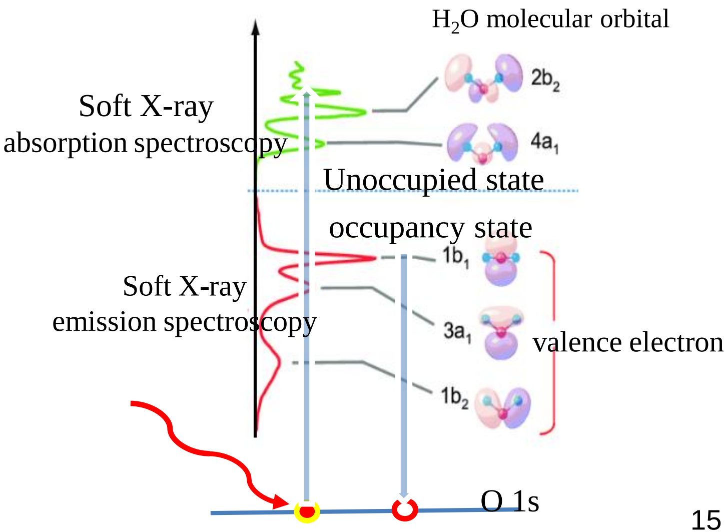


NaCl crystal structure

VUV Soft X-Ray

Function: State of the electron spin? how it moves, interacts, and reacts?

Chemical reactions (catalysis, combustion), electronic structures (superconductivity, topology), magnetism (spin)…

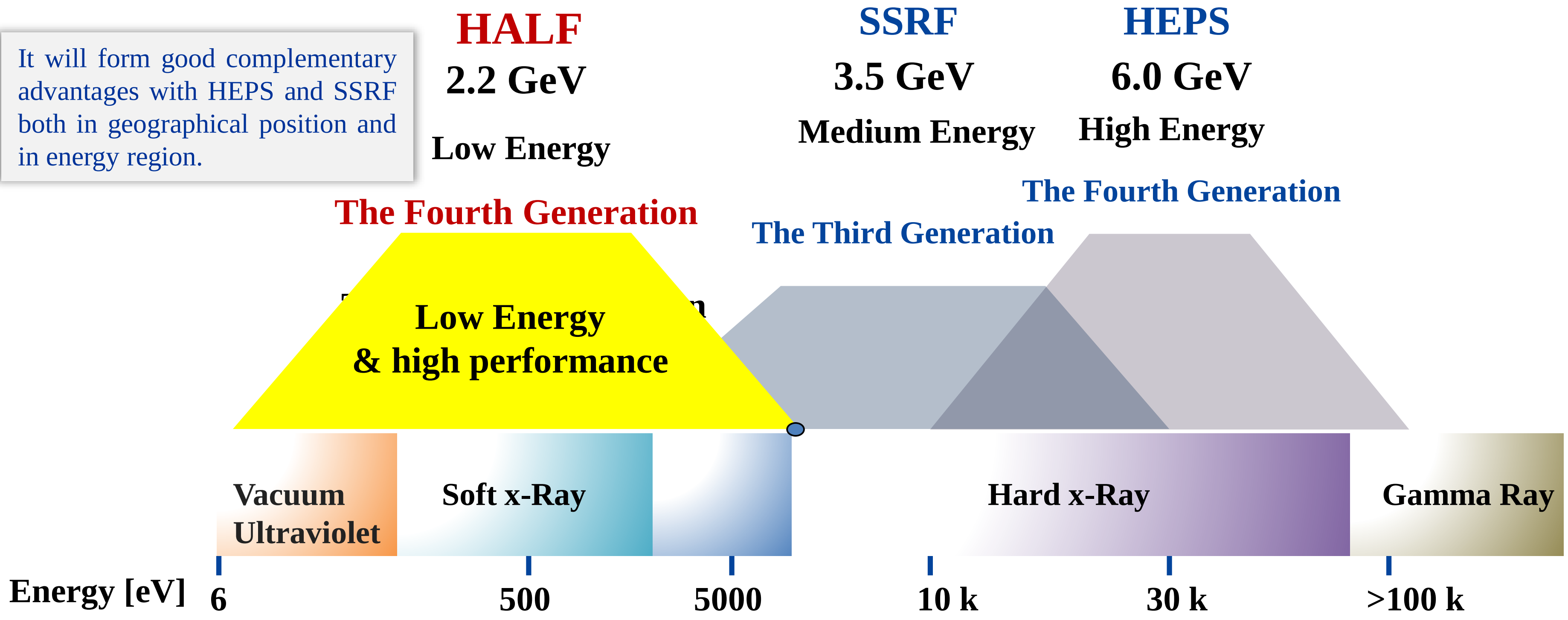


Advantages of low-energy region light source experimental technology

- **Advantages of low-energy light source experimental technology, comparing with medium and high-energy light sources**
  - high energy resolution
  - Measurement of Orbital/Spin/Electron/Chemical Valence States
  - Direct measurement of light elements such as C/N/O and 3D elements
- **Examples of synchrotron radiation experiment using low-energy beamlines**
  - High resolution electronic structure measurement (ARPES, RIXS, IR)
  - Spectral and scattering studies of 3D transition metal elements and magnetic materials
  - Unlabeled molecular sensitive imaging of light element materials and life related systems
  - High resolution photoionization experiment
  - High resolution measurement of chemical valence states

Hefei Advanced Light Facility (HALF) Project

It will form good complementary advantages with HEPS and SSRF both in geographical position and in energy region.

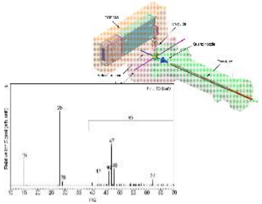


Hefei Advanced Light Source（HALF)—Soft X-Ray Diffraction limited Storage Ring Light Source

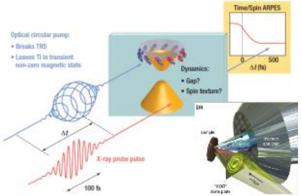
Scientific Goals of HALF

Accurate Measurement of Electronic States/Chemical States/ Light Element Structures of Complex Systems

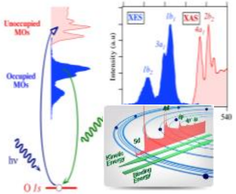
Spectroscopy
Multidimensional electronic structure



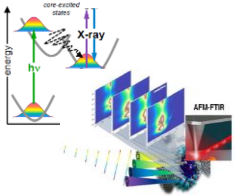
mass spectrum



nano-ARPES

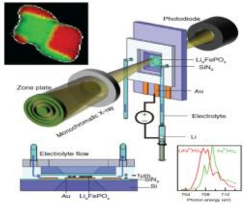


Core level spectroscopy

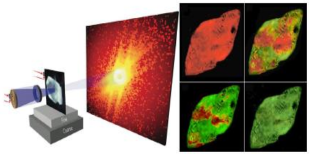


RIXS/REXS

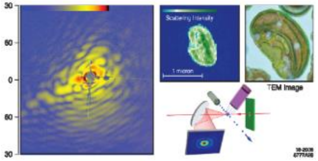
Imaging/Diffraction
Single particle structure imaging



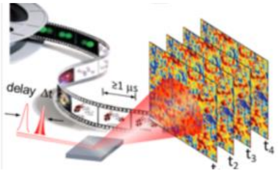
Scanning microscope



Stacked imaging



Coherent diffraction



XPCS

Engineering Goals of HALF

Hefei Advanced Light Facility (HALF)

- Brightness in Soft X-Ray Region >10^{21}
- Coherence in Soft X-Ray Region ~30% (1 keV)
- Straight sections for IDs > 30

Diffraction Limited Emittance of the Electron Beam

$$\varepsilon_{e^-} \le \varepsilon_{ph} = \sigma_{ph}\sigma'_{ph} = \frac{\lambda}{4\pi}$$

Photon Energy / Wave Length	Diffraction Limited Emittance
1.24 keV / 1 nm	100 pm rad

Requirements on the Ring	
Beam Energy	2.2 GeV
Natural Emittance	<100 pm rad
Beam Current	350 mA
Operation Mode	Top off
Straight Sections	~40

Technical Challenges of HALF Accelerator

Technical Challenges of the 4th Generation Light Source

- High Field Gradient, High Quality Magnet Technology
- Small aperture, High Quality, Combined Function Magnet Technology
- Small Aperture, NEG Coating Vacuum Chamber
- BPM Technology with Micron Resolution
- High Precision Mechanical Alignment and Positioning of Accelerator and Beam line Assembly
- Six Dimensional Adjustment, High Precision and High Stability Magnet Support Technology
- Pre-Alignment Positioning Technology on Girder
- High Stability Solid-state RF Power Source
- High Performance Insertion Device Technology（Super-Conducting, …）
- …

Preliminary Research and Development of HALF

中共安徽省委文件

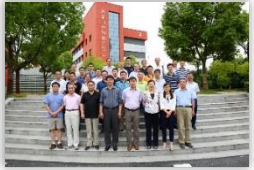
中共安徽省委　安徽省人民政府　中国科学院
关于印发《合肥综合性国家科学中心实施方案
（2017—2020年）》的通知

Total Funds:
356 million RMB

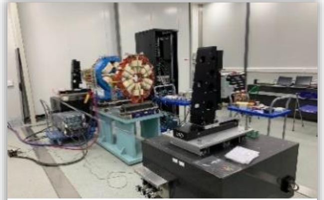
Beginning at the End of 2017

Supported by the Government and Chinese Academy of Sciences

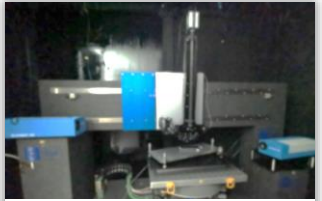
- **2018.6** — Process Supervision
- **2019.5** — Process Supervision
- **2019.7** — Design Scheme Seminar
- **2019.10** — Process Supervision
- **2020.2-3** — User requirements Workshop Series
- **2020.5** — Scheme Demonstration Meeting
- **2020.6-12** — Prototype process test
- **2020.9** — Process Supervision
- **2020.12** — Final Process Test
- **2021.1** — Project acceptance



Preliminary Research and Development of HALF



Magnetic field measurement device

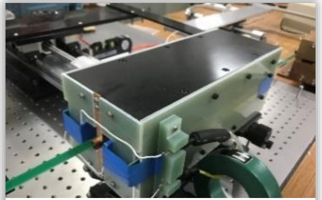


High precision surface detection

Magnet Support

Q Magnet

Septum Magnet



Nonlinear Magnet

D-BPM Processor

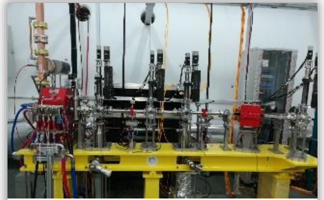


Photo-Cathode RF Gun

Combined Function Magnet

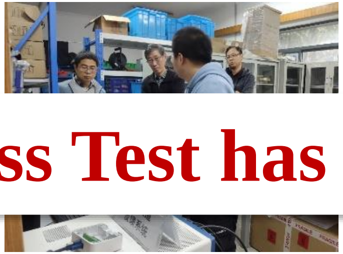
RF Cavity

Power Supply

Monochromator

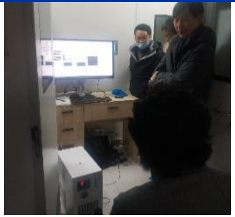
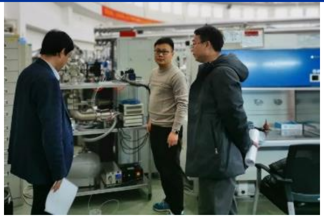
Vacuum Chamber Coating equipment

Preliminary Research and Development of HALF

Project Process Test has Been Completed in Dec. 2020

In Jan. 2021, the project has passed process acceptance. Test results achieve the design specifications. Some results are better than the design requirements.


Hefei Advanced Light Facility (HALF) Project

The Project Started on June 7th, 2023

Engineering Goals	• Operating in the Low-energy Region. the Fourth Generation Synchrotron Radiation Light Source Based on a Diffraction limited storage Ring
Scientific Goals	• Accurate Measurement of Electronic/ Chemical/ Spin States in Heterogeneous Complex Systems
Construction Contents	• 2.2 GeV Storage Ring with circumference of 480 m. In Phase I, 10 Beamline-Stations will be constructed (capable of accommodating at least 35 beamline-stations)
Project Budget	• 2.77892 billion yuan
Construction Period	• 64 months

Overall Plan and Construction Content

☐ Injector

Electron Gun, Pre-injector, Linac and Transport Line

☐ Storage Ring

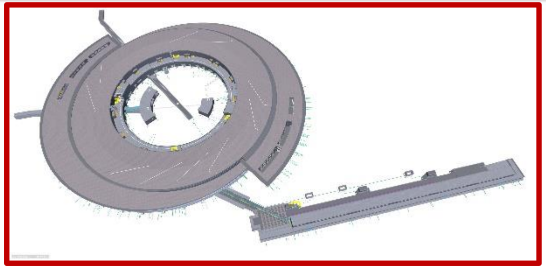
6BA Lattice Structure with 20 Periods, 40 Straight Sections

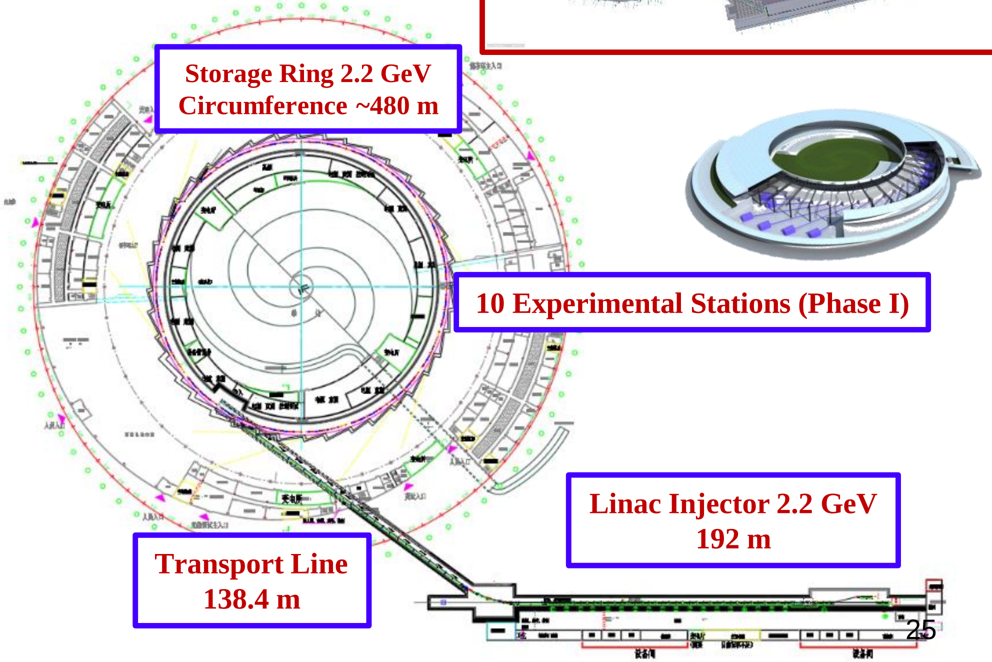
☐ Optical Beam-Lines and Experimental Stations

10 experimental stations including nano angle resolved photoelectron spectroscopy, medium energy X-ray microscopy imaging, nano space resolved soft X-ray coherent scattering imaging, photoionization mass spectrometry, etc.

☐ Public Facilities

Supporting buildings and related power support facilities

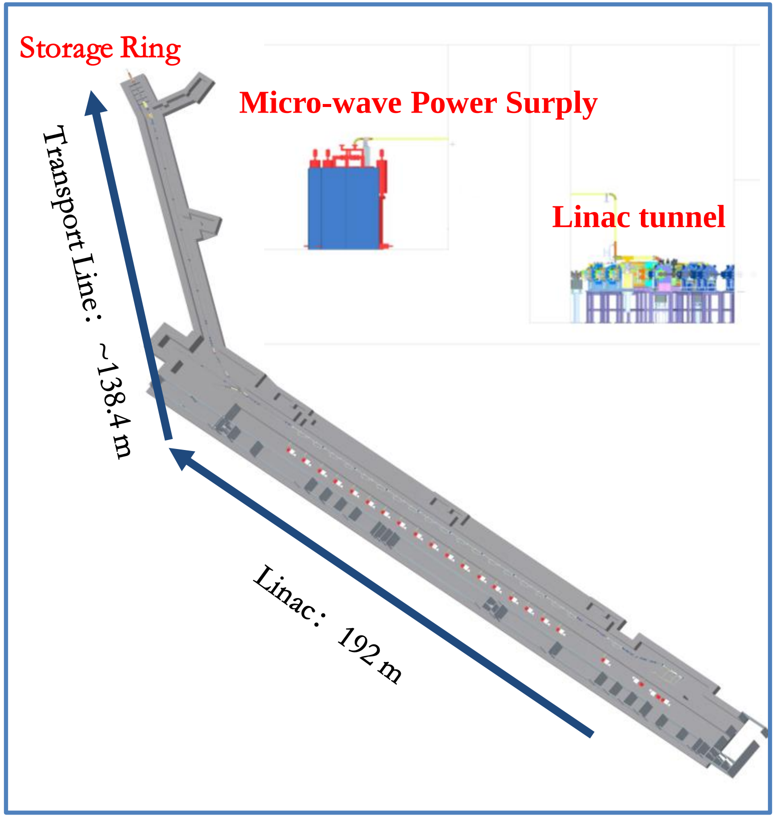




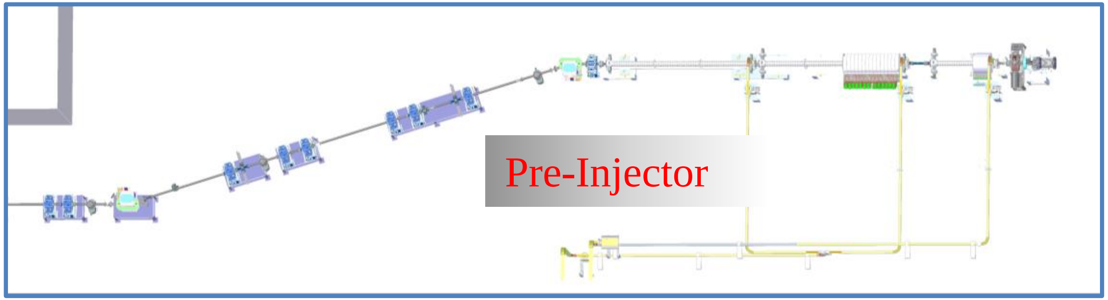
Main Parameters of the Injector

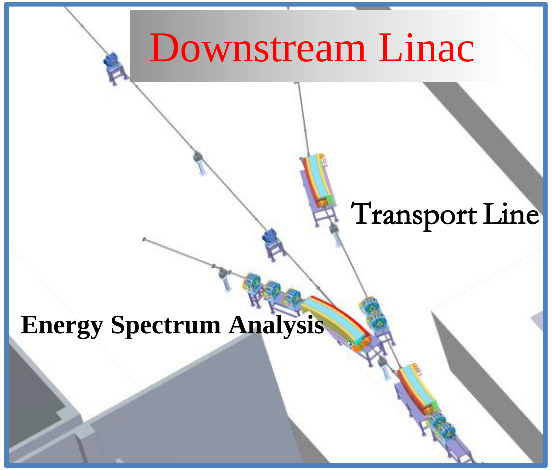
Parameters	Design Specification
Beam Energy [GeV]	2.2
Bunch Charge [pC]	300
Beam Emittance [nm rad]	12
Energy Spread （rms）	≤0.2%
Energy Stability （rms）	≤0.1%
Position Error at Injection Point （rms） （dx， dy） [mm]	0.1
Angle Error at Injection Point （rms） （dx_p， dy_p） [mrad]	0.1

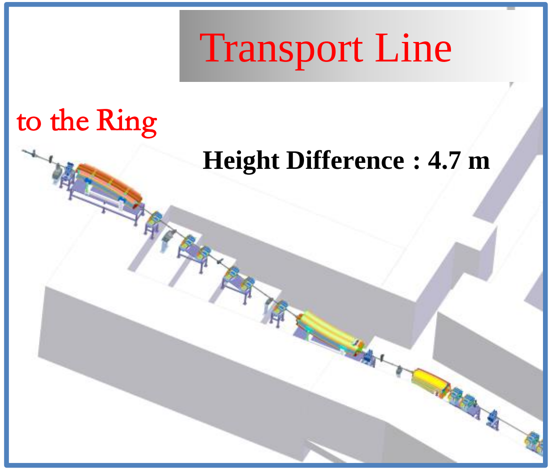
Injector of HALF



3D Layout Diagram of the Injector





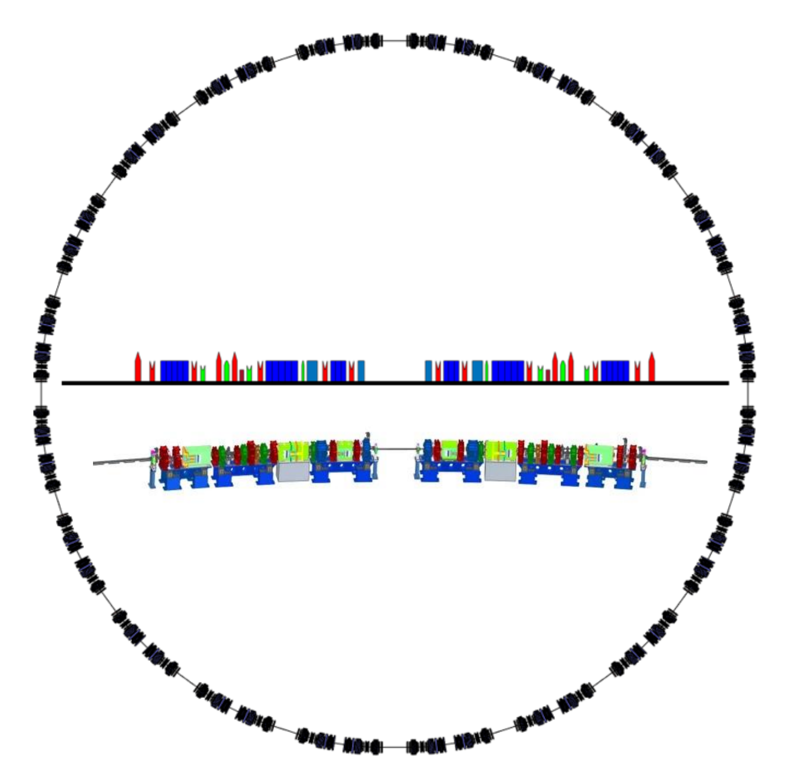


Partial layout of the Injector

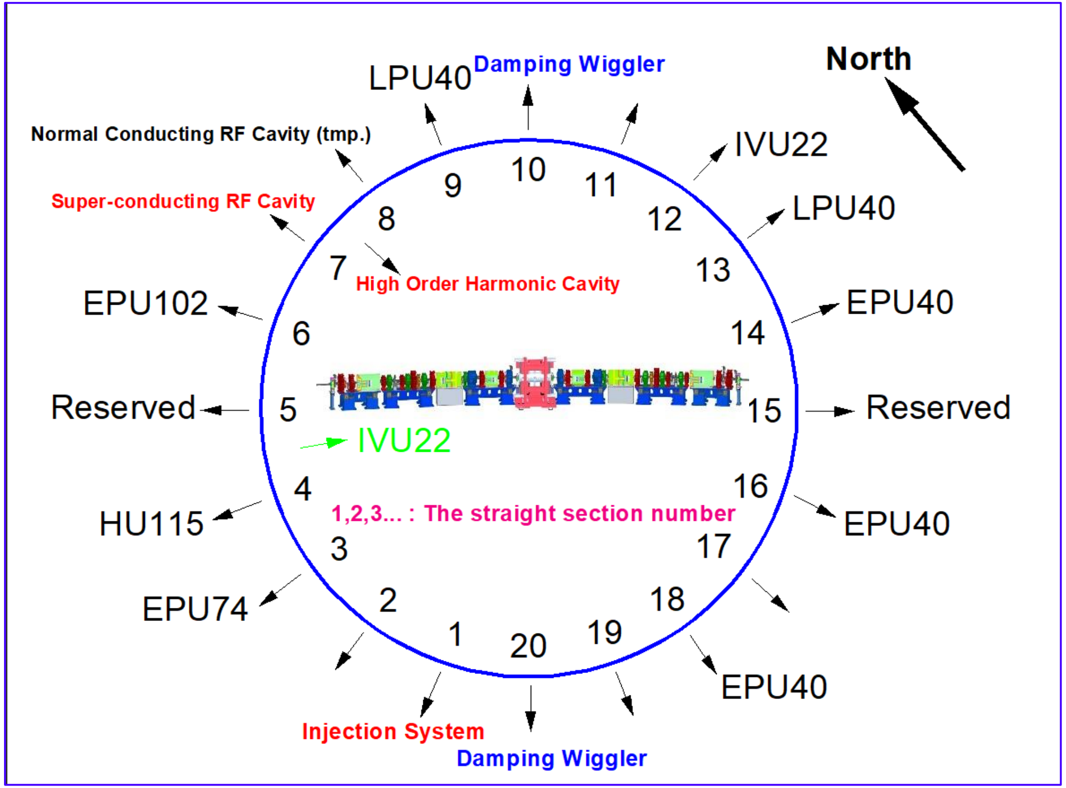
Main Parameters of the Storage Ring

Parameters	Design Specification
Beam Energy [GeV]	2.2
Average Beam Current [mA]	350
Circumference [m]	479.86
Lattice Structure	6BA
Natural Emittance of the Beam [pm rad]	86.3
Beam Orbit Stability （rms）	<10% Transverse Beam Size
Straight Sections	20×5.3 m+20×2.2 m
Brightness @ 1 keV [Flux/mm^{2}mrad^2]	1.15×10^{21}
Coherent fraction of synchrotron emission @ 1 keV	30%

Storage Ring of HALF

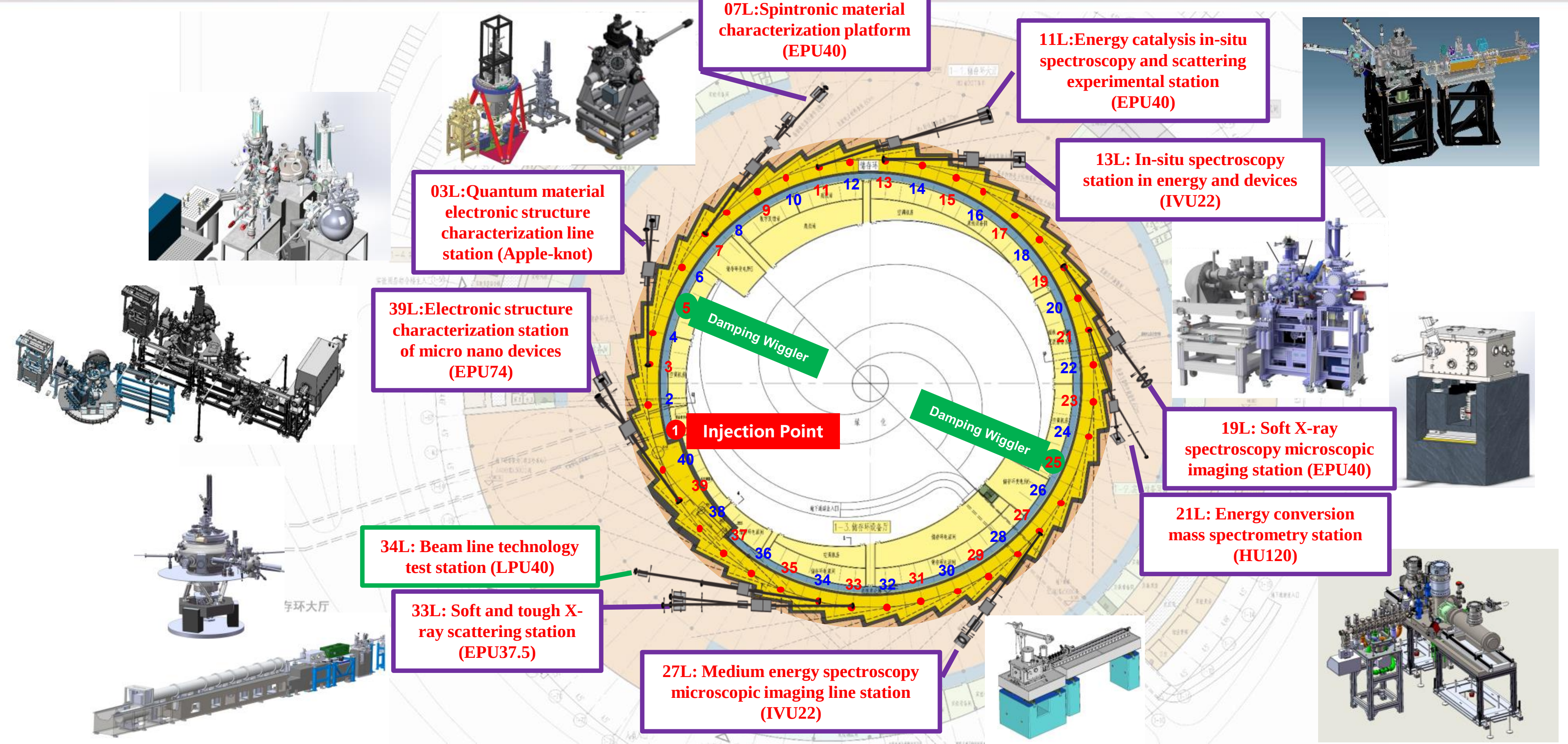


Magnets Distribution along the Ring (6BA)

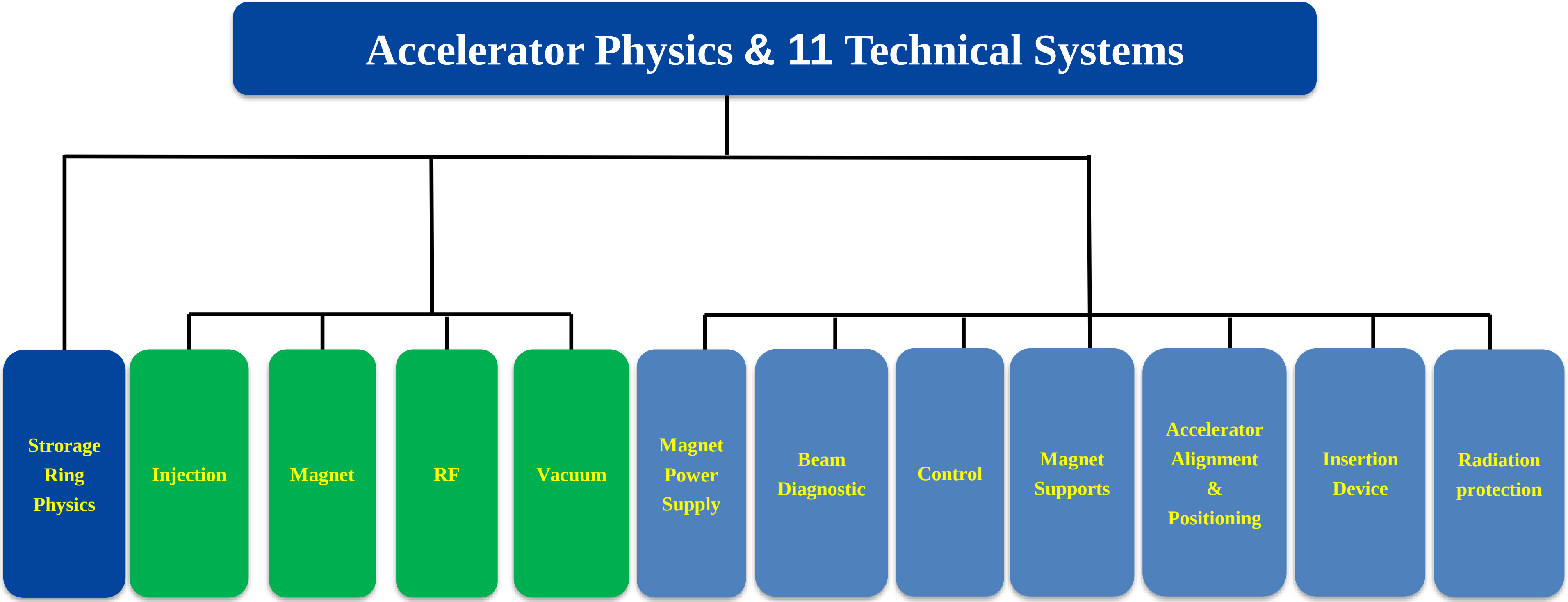


Elements Distribution at the Straight Sections

Hefei Advanced Light Facility (HALF) Project



Technical Systems of the Storage Ring



Storage Ring Physics - Lattice Design

A modified hybrid 6BA lattice Structure

- **SLS-2 lattice（TME-like cell）+ ESRF-EBS lattice (hybrid MBA)**

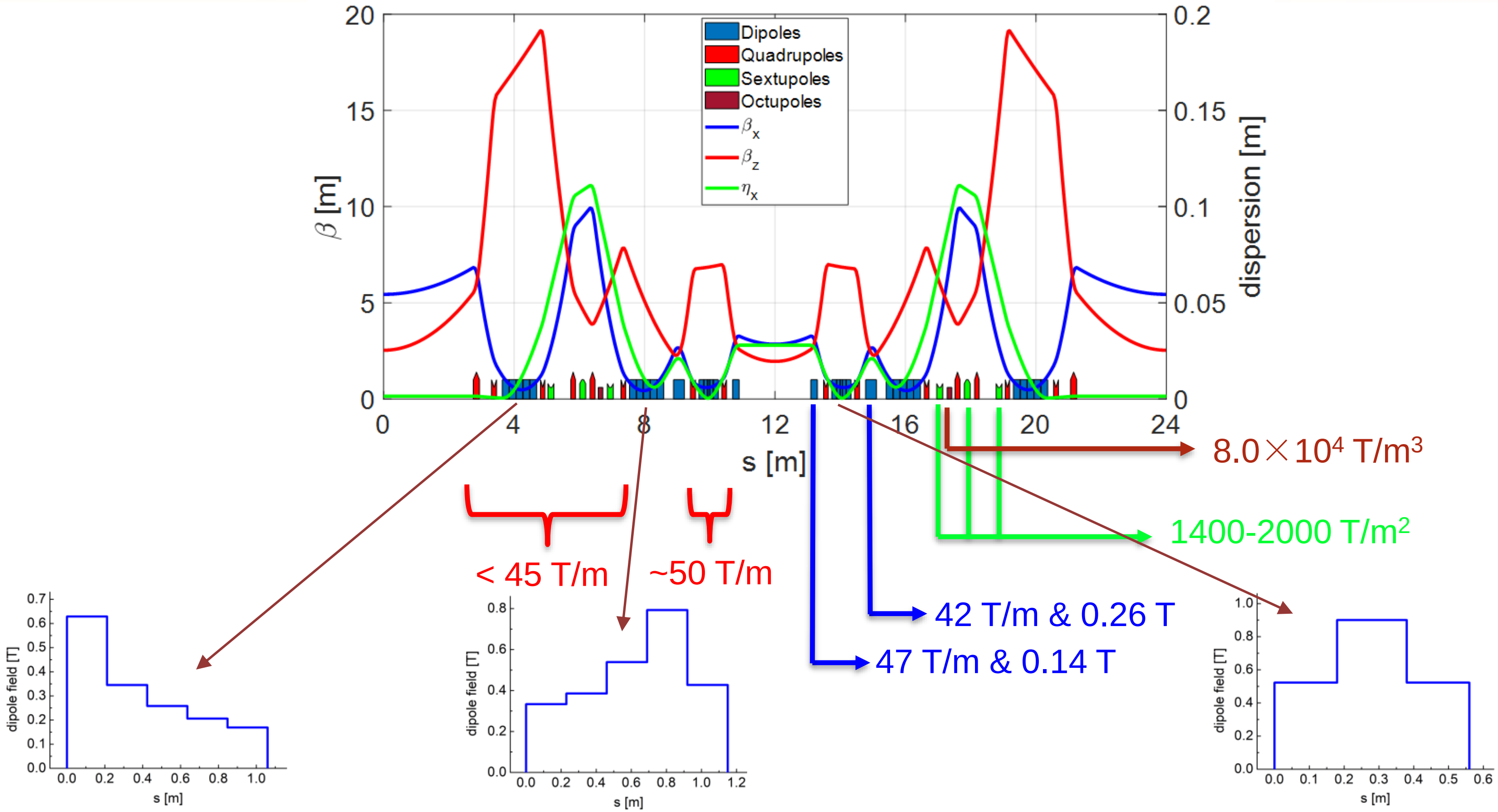
  Ultra-low beam emittance + Good nonlinear beam dynamics performance + More straights

- **Effectively shortening the damping time for storage ring with large circumference and low energy**

- **20 cells，Two straight sections per cell (5.3 m, 2.2 m)→ 40 straight sections**

  The ratio of the total length of the straight sections to the circumference of the storage ring is ~32%

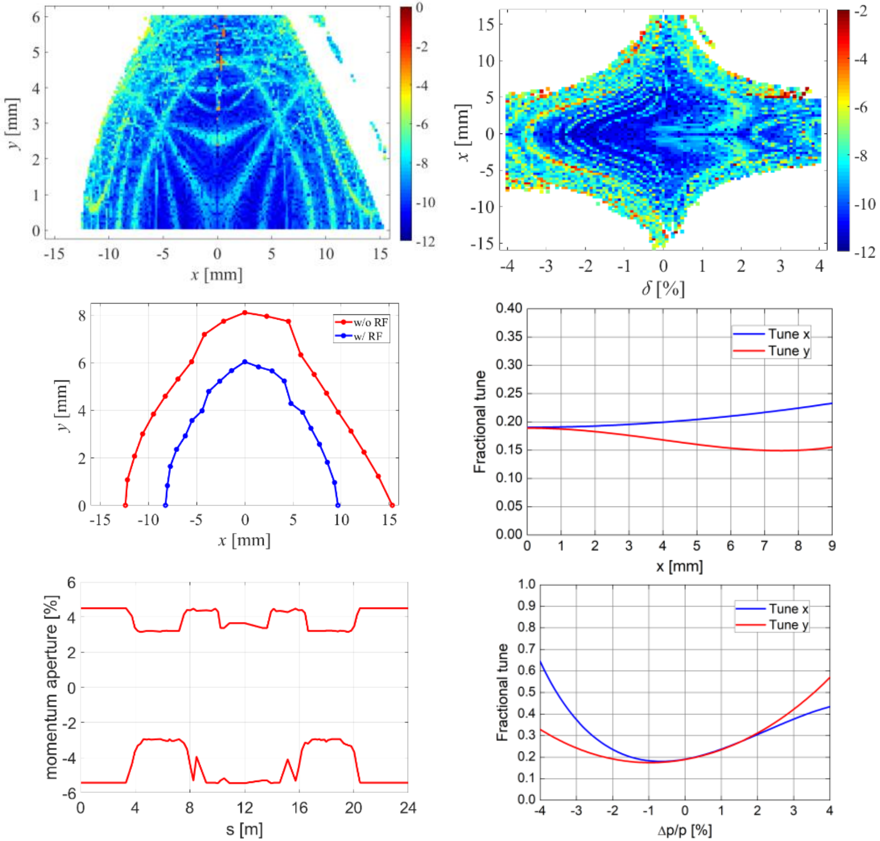
Storage Ring Physics - Lattice Design



Storage Ring Physics - Lattice Design

Storage Ring Parameters

Beam Energy	2.2 GeV
Circumference	479.86 m
period Number	20
Natural Emittance	86.3 pm·rad
Tunes（H/V）	48.19/17.19
Natural Chromaticity（H/V）	-81.6/-56.6
Momentum Compaction Factor	9.4×10^{-5}
Damping partition number（H/V/L）	1.36/1.00/1.64
Damping Time（H/V/L）	28.5/38.8/23.7 ms
Energy Loss of Bending Magnet Radiation/turn	186.7 keV
Energy Spread	0.61×10^{-3}
Number of Straight Sections	40 (5.3 m, 2.2m)



Storage Ring Physics – Machine Errors and correction

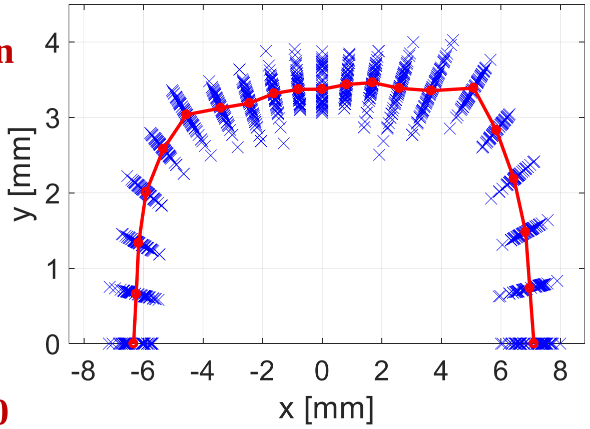
- **Magnets misalignment:** Within girder <30 μm, Between girders <50 μm, roll error <0.1 mrad
- **Dipole& Quadrupole fractional strength error:** <0.05%

BMP（Yellow diamond shape,12）, Corrector（ Magenta rectangle,12）, Girder（ Black Box, 6 ）

- **Orbit Correction, Optics Correction, Coupling and Dispersion Correction**

After Correction

	Closed Orbit Correction in Hor.	Closed Orbit Correction in Ver.	β-beating in Hor.	β-beating in Ver.	Dispersion
RMS Value	41 μm	53 μm	1.2%	1.1%	0.3 mm
Max. Value	250 μm	280 μm	3.4%	3.1%	2.0 mm



6D DA after Correction (Taking RF into account)

- **6D Dynamic Aperture after Correction: ~7 mm (rms value, in hor.), ~3.0 mm (rms value, in ver.); Meet the requirement of off-axis injection**

Storage Ring Physics – Beam Collective Instabilities

Intra-beam scattering effect: Considering bunch lengthening with harmonic cavity, Emittance of 350 mA fully coupled beam ~ 61 pm rad

Taking into account fully coupled beam, 80% beam bunch filling mode, high-order harmonic cavity lengthen the beam bunch, IDs impact and IBS effect.

Conditions	Beam emittance
0 mA	50 pm rad
350 mA	88 pm rad
350 mA + damping wiggler	72 pm rad
350 mA + damping wiggler + IDs	61 pm rad（IDs working）

Beam life time (10% coupling, Triple elongation, 350 mA)， ~5 hours

Beam instabilities

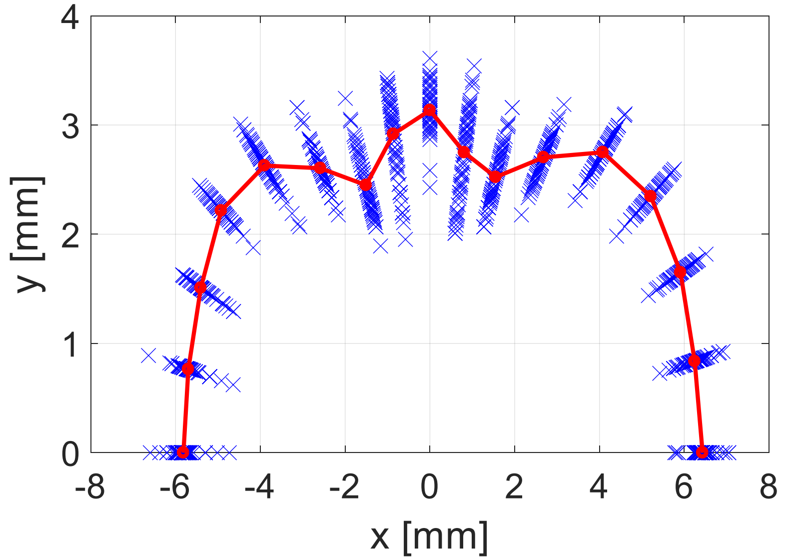
- **Longitudinal microwave instability** When the RMS bunch length is 2 mm, it will encounter microwave instability, which can be avoided by stretching the beam length
- **Transverse single bunch instability** Chromaticity +3, bunch length 6 mm, threshold exceeds 5 mA, far higher than the target
- **Impedance wall instability** Chromaticity +3, bunch stretching and transverse bunch by bunch feedback system can effectively suppress impedance wall instability
- **High order mode instability** The high-order modes of superconducting high-frequency cavities are generally weak, and their instability threshold is higher than the target current
- **Ion-trapping Instability** Non-uniform filling mode and transverse bunch by bunch feedback system will effectively suppress the instability

Storage Ring Physics – IDs effects

IDs（Including Damping Wigglers）effects

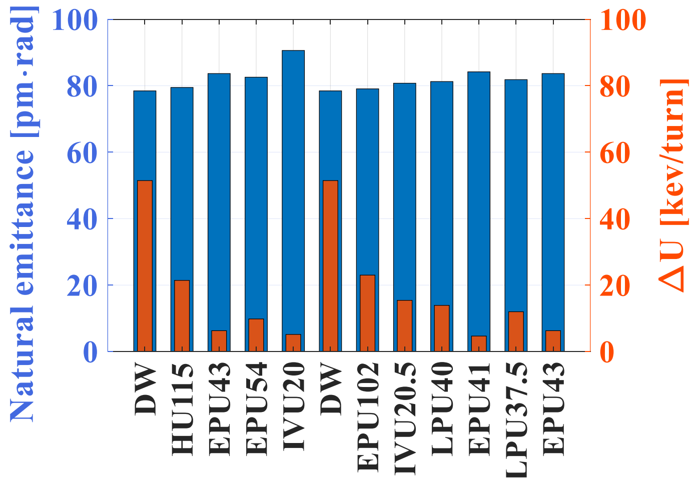
Influence of IDs on beam dynamic aperture

IDs cause a decrease of approximately 0.7 mm in the dynamic aperture at the injection section



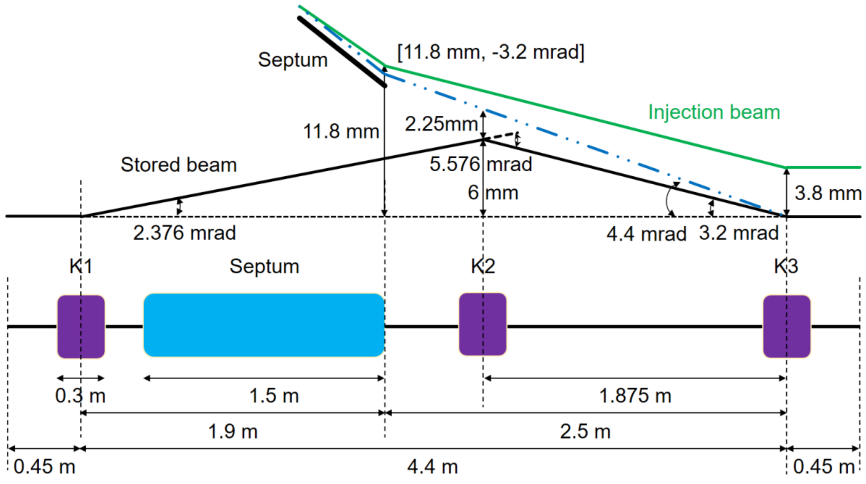
Single ID impact to beam emittance and energy loss

- Emittance variation -8~5 pm·rad
- Energy loss variation 5~52 keV
- Energy Spread variation -0.8%~15%



Storage Ring Physics – Injection Process Simulation

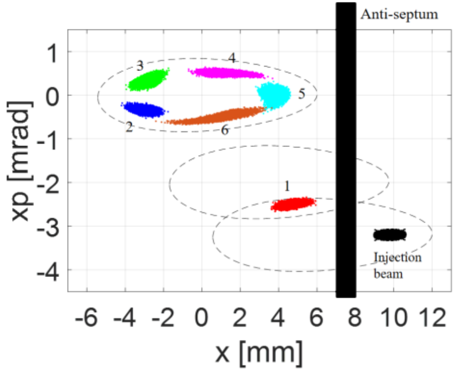
Off-axis Three-kicker Bump Injection (the layout allows nonlinear kicker injection in the next stage)



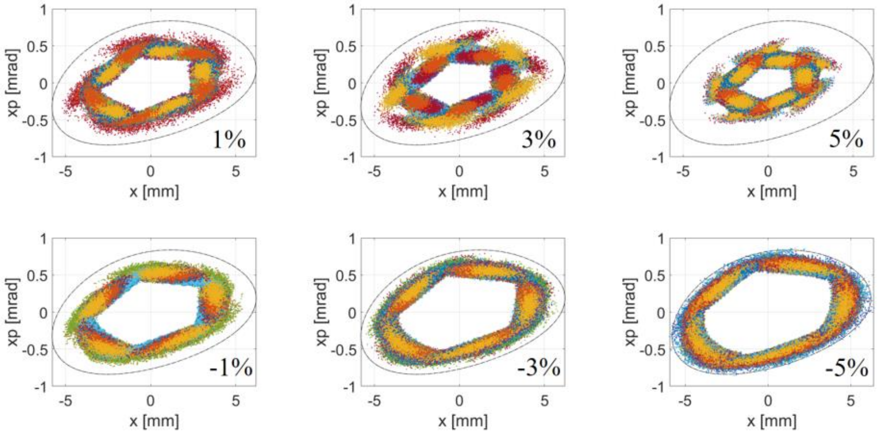
Layout of Injection System

Tracking simulation

The residual error of the local bump is controlled within ± 5%, and the beam injection efficiency can reach over 95%.



Injection process in the first 6 turns



Influence of residual errors of the local bump

Injection System

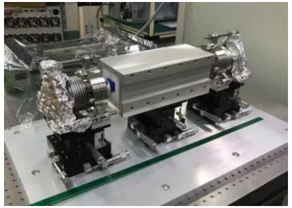
- Off-axis Three-kicker Bump Injection Mode
- Kicker Magnet with double pipes

Main Parameters of Injection System

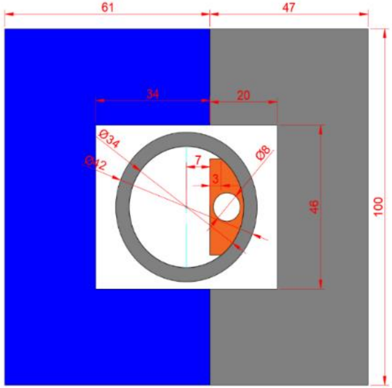
Parameter	unit	Septum	Kicker1	Kicker2	Kicker3
Beam Energy	GeV	2.2	2.2	2.2	2.2
Deflection Angle	mrad	174.5	2.376	5.576	3.2
Integral magnetic field	T·m	1.28	0.0174	0.041	0.0235
B	Gauss	9843	580	1363	782
Magnet Length	mm	650×2	300	300	300
Gap	mm	8	46	46	46
Bottom width of pulse	μs	60	5.6	5.6	5.6

Injection System

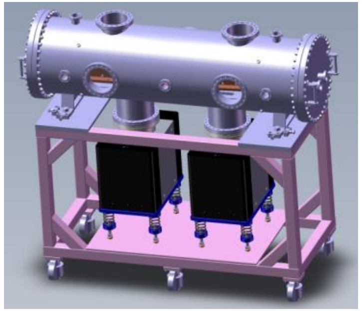
Kicker Magnet with double pipes

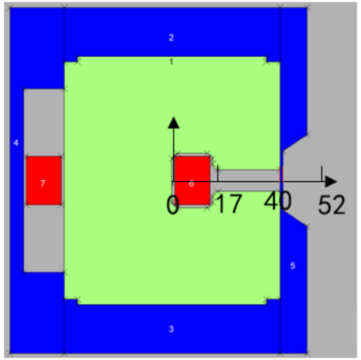


Ceramic vacuum chamber coated with titanium film

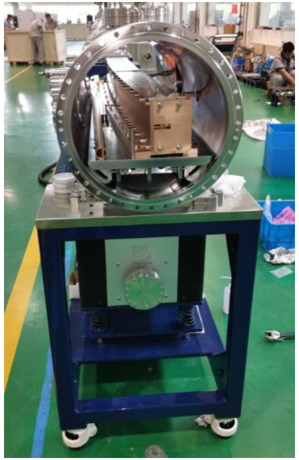


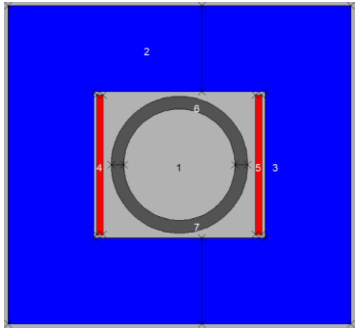
Cross section of the Kicker Magnet (K2)



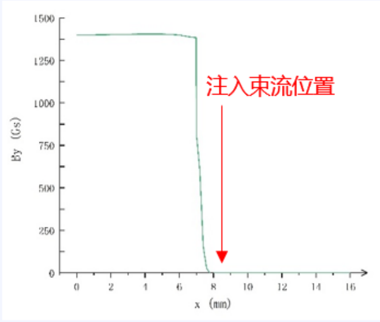


Eddy-current septum magnet

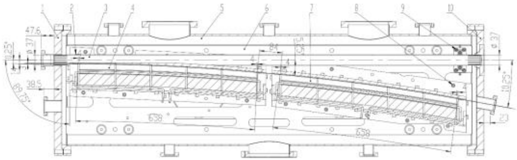




Cross section of the Kicker Magnet (K1,K3)



Magnetic field shield



Septum Magnet Prototype

Radio Frequency System

□ 500 MHz Super-Conducting RF Cavity

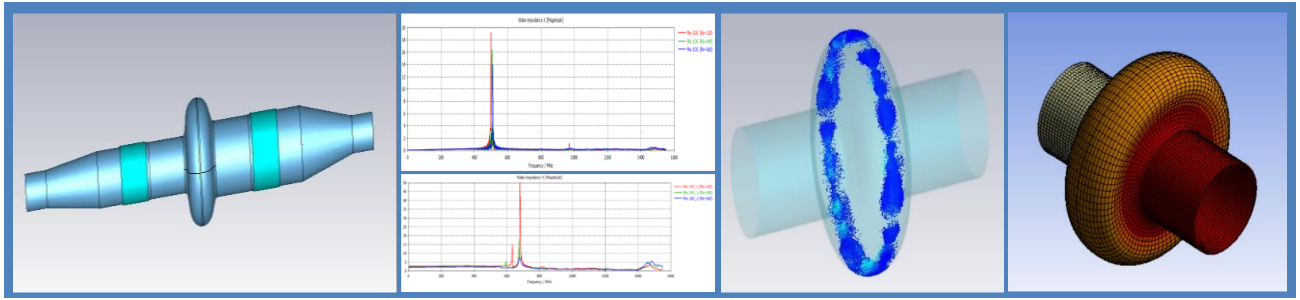
（Low Power Loss, High Cavity Voltage, Save Space, Efficient HOM Damping, High Q & Large Beam Aperture）

□ 1.5 GHz The 3rd Harmonic Cavity

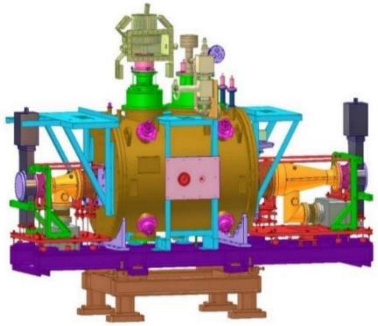
（Large R/Q， Lengthening Bunch Length, Long Beam Lifetime, Suppression of Beam Collective Instabilities）

Parameter	Unit	Main RF System	The 3rd Harmonic RF System / passive
RF Frequency	MHz	499.8±0.2	1499.4±0.5
Operation Temperature	K	4.5	4.5
Cavity Material		Niobium	Niobium
Maximum RF Voltage	MV	2	1
Number of Cavities		1	1
Operation Voltage	MV	1.5 ($Q_0>5\times10^8$)	0.5 （R/Q<45 Ω）
Maximum Input Power	kW	140	Passive cavity

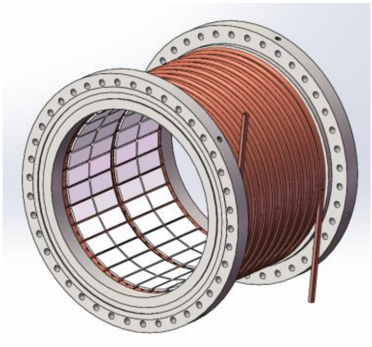
Radio Frequency System



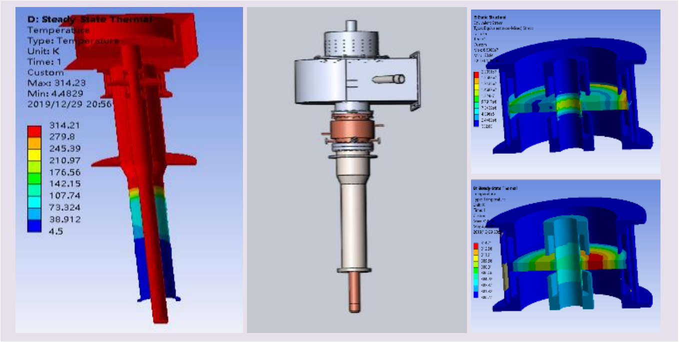
Optimization Design of the 500 MHz Superconducting Cavity Structure



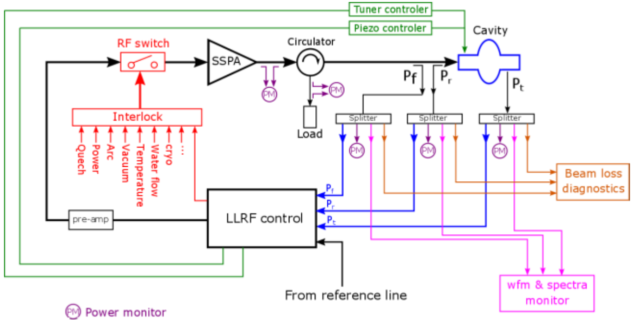
Superconducting Module



High-order Mode Damper



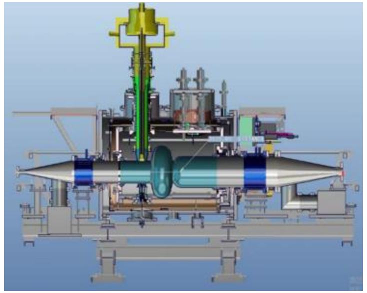
Simulation of the Power Coupler



Digital Low Level Control System

Radio Frequency System

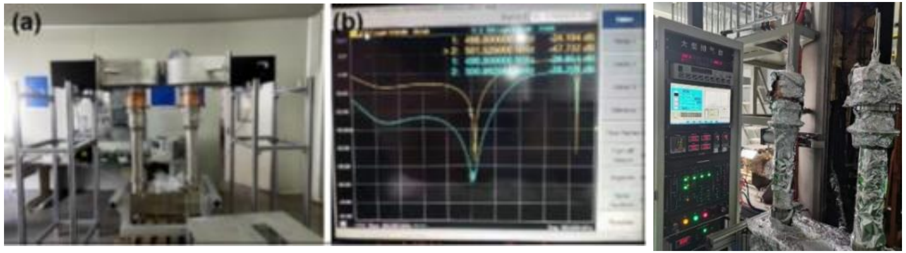
- The Manufacturing of Superconducting RF Cavity has been completed
- The Prototype Development of Solid-state Power Source, Power Coupler, and High-order Mode Damper has been completed



Superconducting RF Module

Vertical Testing of the RF Cavity

500MHz/250kW Solid State Power Source

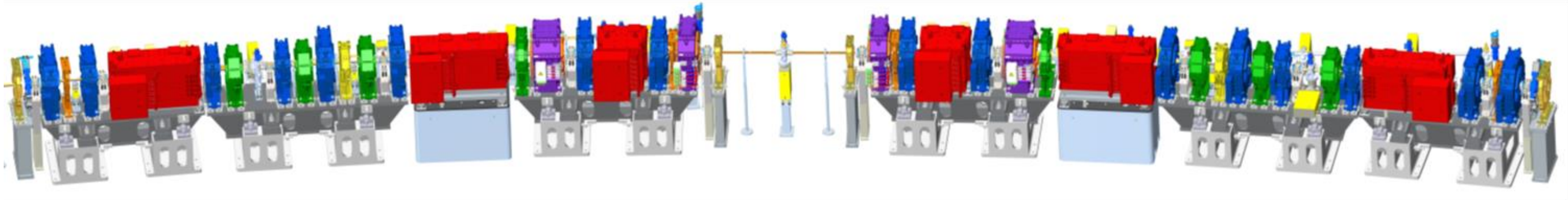


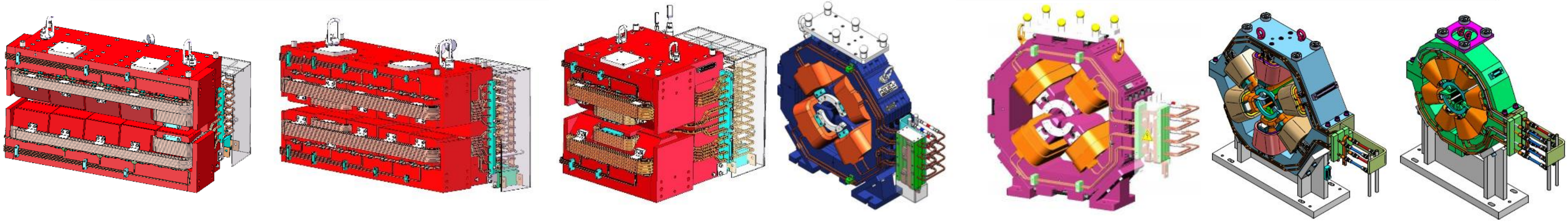
RF and Vacuum Testing of High-power Coupler

High Order Mode Damper Vacuum and Power Testing

Magnets of the Ring

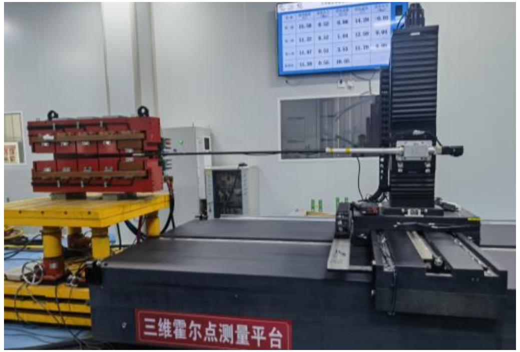
- 44 Various types of magnets/Cell， 880 Magnets along the Ring
- Longitudinal Field Gradient Bending Electromagnet (LGB)
- High Field Gradient Quadrupole Magnet with High Quality and Small Aperture
- Combined Function Dipole-Quadrupole Magnet



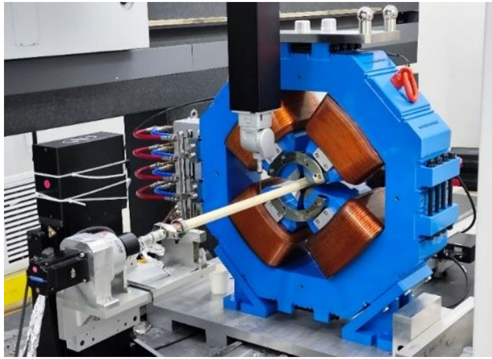


LGB1 (2/cell) | LGB2 (2/cell) | LGB3 (2/cell) | Quadrupole magnet (16/cell) | Combined function magnet (4/cell) | Sextupole (8/cell) | Octupole (2/cell)

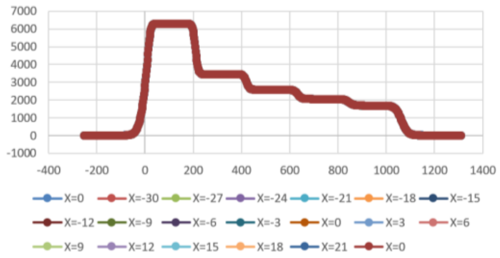
Magnetic Field Measurement



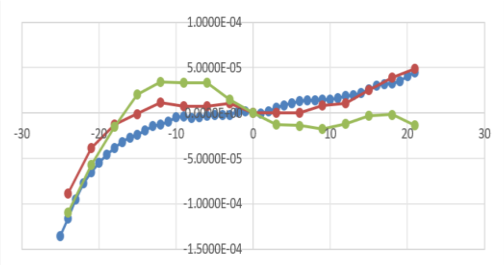
Magnetic Field Measurement for LGB with Hall Probe Measuring Device



Magnetic Field Measurement for Quadrupole Magnet



Distribution of magnetic field along the longitudinal direction



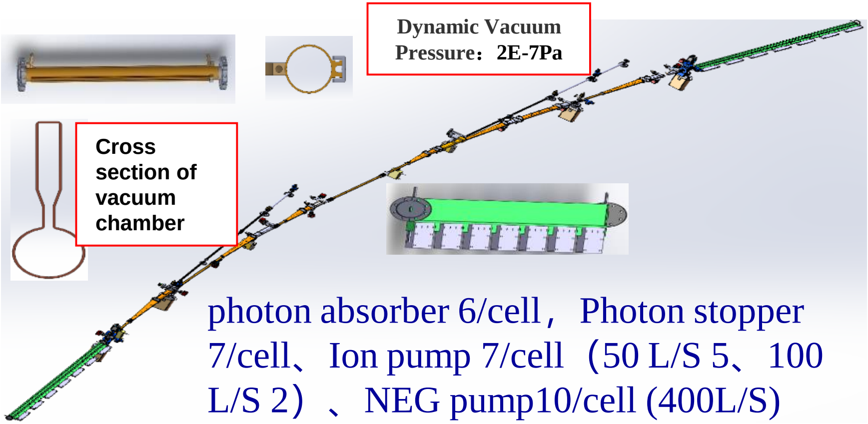
Uniformity of integral field within the good field Region

HALF Q1 20231222						
good field region ±13 mm						
Current A	B3/B2	B4/B2	B5/B2	B6/B2	Magnet Center(mm)	
					X0	Y0
40	2.39E-04	5.37E-05	6.12E-05	2.05E-04	0.02252	0.00811
60	2.37E-04	6.25E-05	6.13E-05	1.77E-04	0.02326	0.00706
80	2.74E-04	6.98E-05	4.59E-05	1.39E-04	0.02279	0.00778
90	2.96E-04	6.64E-05	5.70E-05	1.31E-04	0.02263	0.00825
100	3.42E-04	6.18E-05	5.56E-05	8.32E-05	0.02171	0.00895
125	4.01E-04	5.63E-05	6.20E-05	1.13E-05	0.0196	0.0051
140	3.82E-04	6.52E-05	5.98E-05	5.65E-05	0.02057	0.0037

High-order harmonic component Measurement

Vacuum System

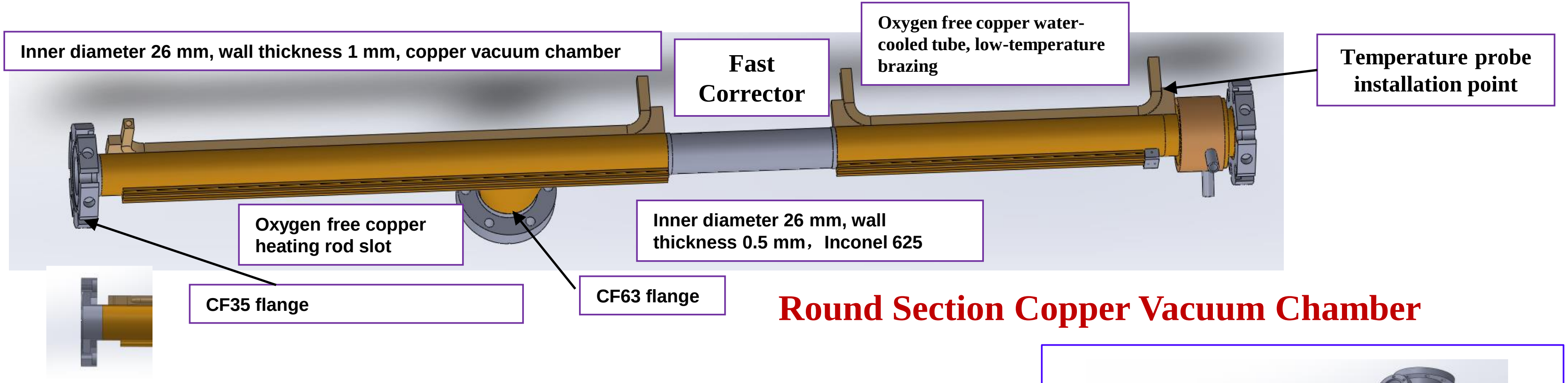
- **Requirement from High Magnetic Field Gradient➔ Small Magnetic pole Gap➔ Small Aperture, NEG Coating Vacuum Chamber （Straight Section, Arc Section, Section with Light Extraction…）**
- **Activation, Water Cooling, Photon Absorber, Shielding Impedance corrugated tube …**



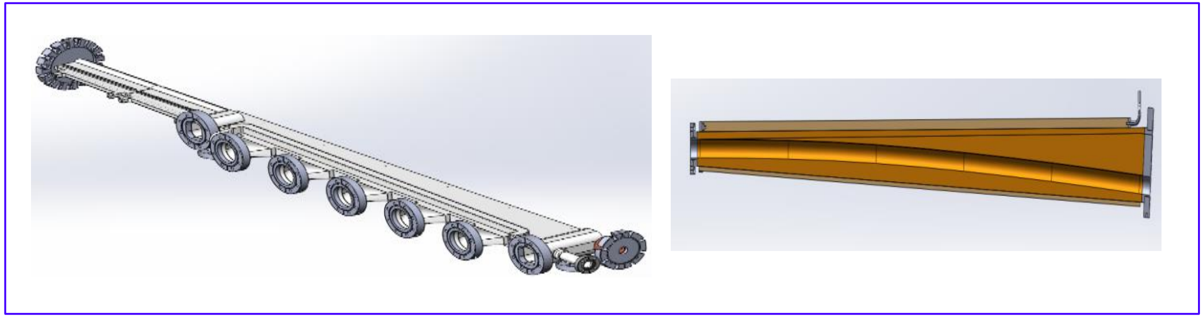
Arc Section

Straight Section with SR Extraction

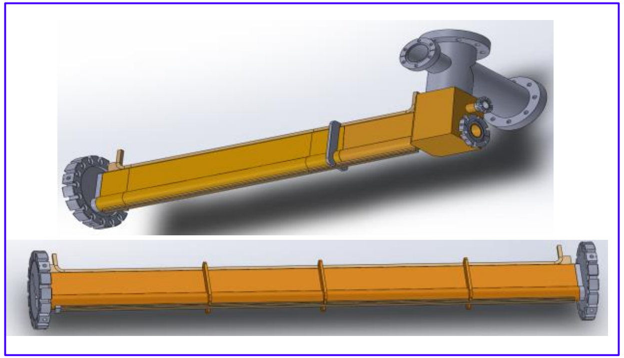
Vacuum System



Round Section Copper Vacuum Chamber

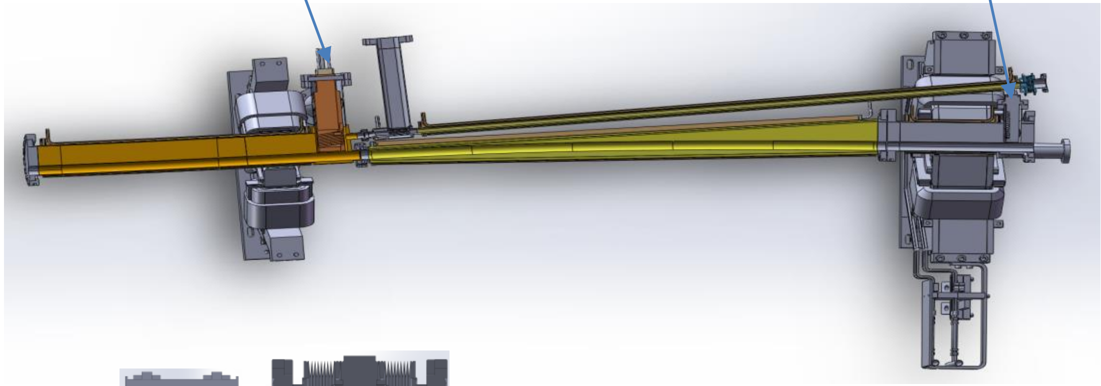


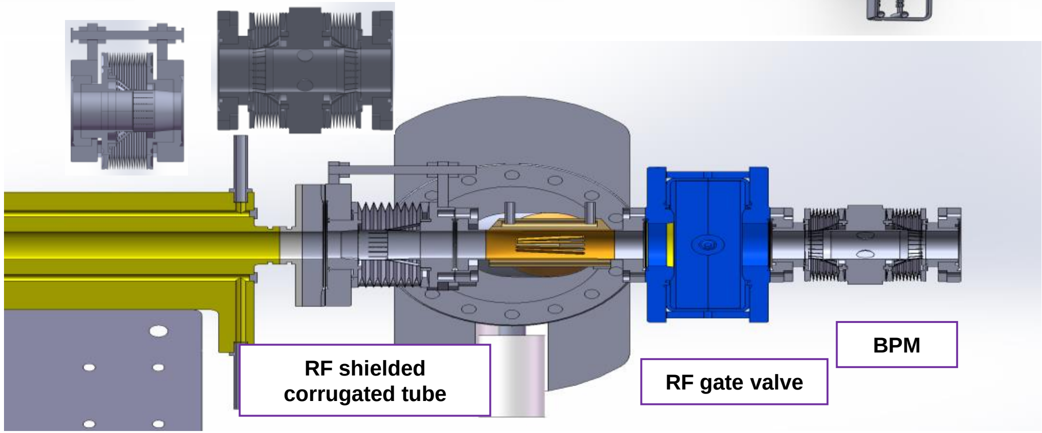
Vacuum chamber with variable cross-section and front chamber

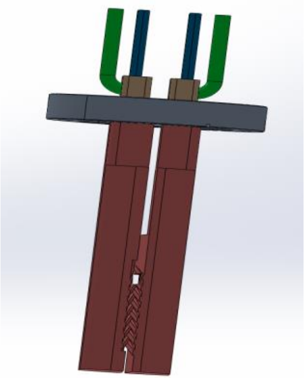


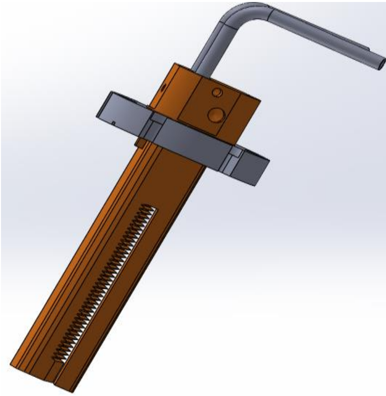
Vacuum chamber with equal cross-section and front chamber

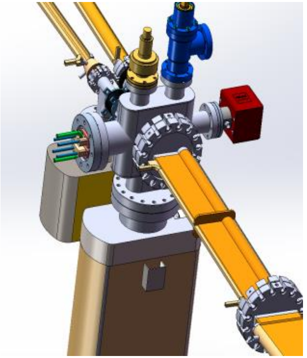
Vacuum System



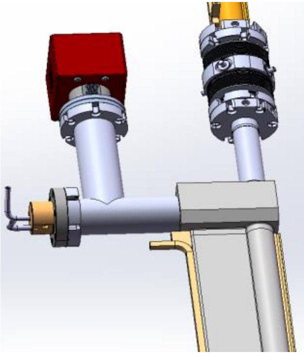








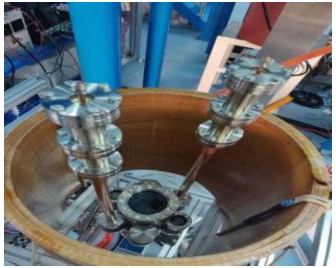
photon absorber



photon absorber

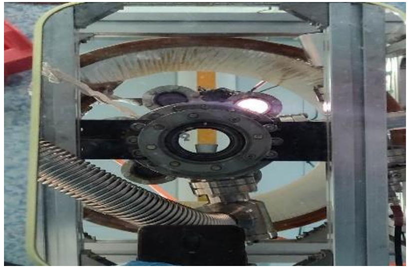
Vacuum Coating Equipment

Cleaning

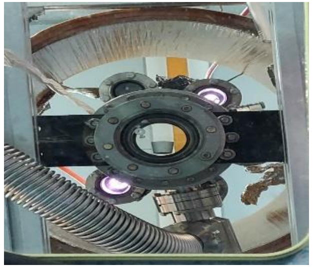


Installing

Preevacuating

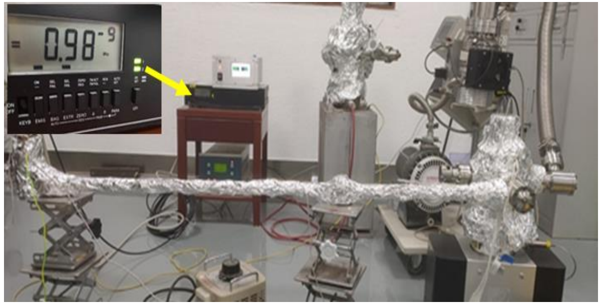


surface pretreatment

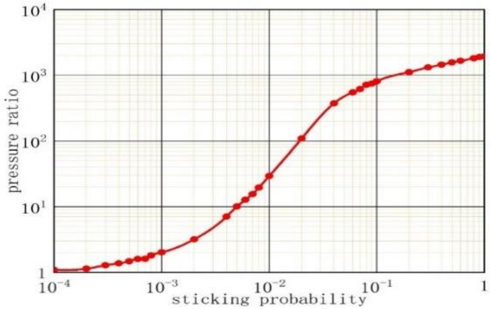


Discharge

Disassembling



Vacuum degree： 0.98E-8 Pa



Other Systems of the Storage Ring

Systems	Function	Main Parameters	Status
Magnet Power Supply	Providing high-precision and stable excitation current for various types of magnets	Ripple and stability of the main magnet power supply are better than 10 ppm Fast orbit corrector's power supply, small signal bandwidth: 5 kHz	Mature technology
Control System	Realizing remote monitoring and control of various devices of the storage ring, as well as commissioning and control of the electron beam	Slow interlock response time ~10ms Fast interlock response time ~10μs	Mature technology
Beam diagnostic system	Measuring and diagnosing various beam parameters, such as beam position, current and emittance, etc.	Beam position resolution: 50nm@10Hz, 100nm@10kHz, Beam current resolution: 1 μA Tune resolution: 10^{-4}; Beam cross-section resolution: better than 2 μm, Orbit feedback system: < 10% beam size	Mature technology
Mechanical support	Providing mechanical support for magnets, vacuum chambers, beam measurement components, etc.	Resolution of position adjustment is better than 1 μm The first-order vibration frequency is greater than 55 Hz	Mature technology
alignment system	Aligning and installing all online devices in place according to accuracy requirements.	Alignment/positioning accuracy in girder: <30 μm, 0.1 mrad Alignment accuracy between girders: <50 μm, 0.1 mrad	Mature technology
Radiation protection system	Radiation shielding, radiation monitoring, personal safety interlock, personal dose monitoring, environmental medium monitoring, etc.	Annual radiation dose of staff< 5 mSv, User's annual dose < 1 mSv, General public annual dose< 0.1 mSv	Mature technology
Insertion devices	Providing users with synchrotron radiation	Meeting requirements of users of ten experimental stations	Mature technology

Construction Schedule for the Storage Ring

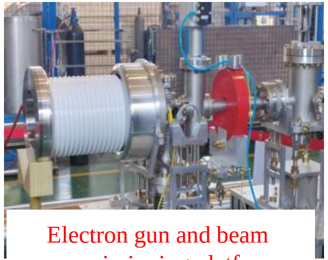
Project Period 64 months

☐ Engineering Design	4 months
☐ Equipment Processing and Manufacturing	28 months
☐ Off-line Testing	6 months
☐ Equipment Installation and On-line Adjustment	12 months
☐ Storage Ring Commissioning	8 months
☐ Joint Commissioning with Optical-lines & Experimental Stations	6 months

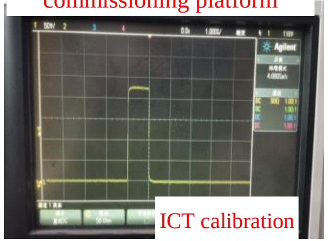
Completion of the project Oct. 2018

Current Progress of the Injector

Gridded thermionic DC gun



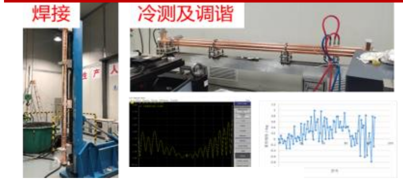
Electron gun and beam commissioning platform



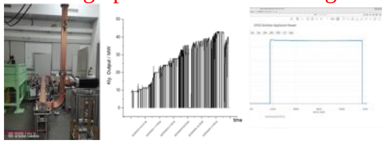
ICT calibration

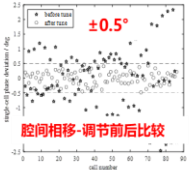
- Beam commissioning for the gun have been completed.
- Performance parameters meet the design requirements.
- Process testing has been passed

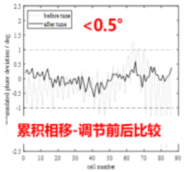
Traveling wave accelerating structure



High power RF conditioning

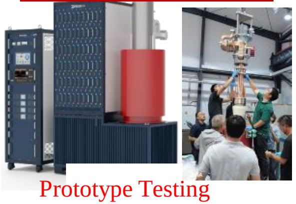




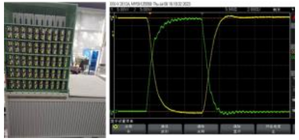


- The first set of process testing has been completed
- High power microwave testing results meet requirements
- Batch production and processing have already started

Solid-state modulator



Prototype Testing



- Test indicators meet the engineering requirements (10Hz, continuous 72 hours fault-free RF conditioning)
- Process testing of the first modulator has been passed successfully
- Batch production has been started

Vacuum Chamber

- The processing and factory testing of the first unit have been completed
- Batch production has been started

Support for accelerating tubes and magnets

Aluminum alloy support

Secondary support component

- The processing and factory testing of the first unit have been completed
- Batch production has been started

Current Progress of the Injector

Magnets and Solenoids

- All magnets (dipoles, quadrupoles, solenoids, correctors) have been processed and factory tested
- Performance indicators meet engineering requirements

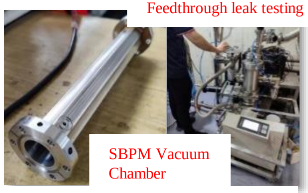
Klystron

Parameters	Technical index	1#	2#	3#	4#	5#
frequency	2856MHz	2856MHz	2856MHz	2856MHz	2856MHz	2856MHz
Output Power	≥80 MW	80.6	80.3	80.5	80.2	80.5
driving power	≤500 W	359	335	313	313	313
Beam pulse width	≥6.2 μs	6.2	6.2	6.2	6.2	6.2
repetition frequency	50 pps	50	50	50	50	50

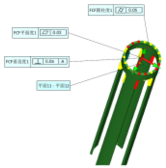
- All 20 klystrons have been processed and factory tested

BPM detector

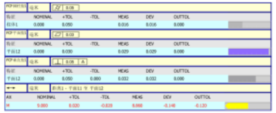
Feedthrough leak testing



SBPM Vacuum Chamber



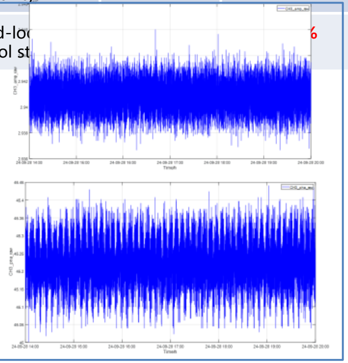
The first item testing



- Mechanical and vacuum performance of the first item meets the standards

Digital low-level RF system

Parameters	Technical index	Measurement result
Desktop Test: Phase Control Stability	0.02°	**0.016°**
Desktop testing: amplitude control stability	0.02%	**0.016%**
Online closed-loop: phase control stability	0.2°	**0.061°**
Online closed-lo[...] amplitude control st[...]		[...]%



6-hour closed-loop test results under high power conditions

- Desktop testing and high-power testing have been completed
- Performance indicators are better than the design requirements

Current Progress of the Storage Ring

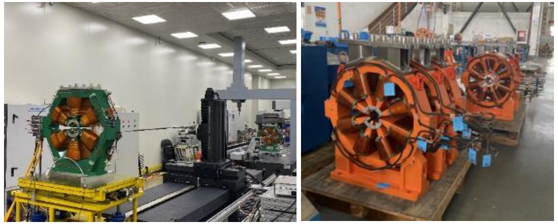
LGB and Quadrupole magnets

LGB1、LGB2 and LGB3

High field gradient quadrupole magnets

- Factory tests for All LGB and first batch of the Q, S, O magnets have been completed

Sextupole and Octupole magnets

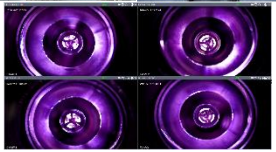


Girder

- Performance of the first item of girders meets the requirements

Vacuum system

Four channel coating equipment



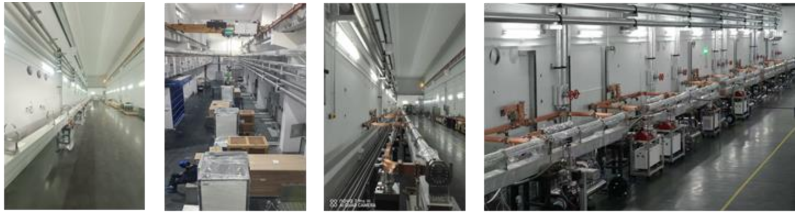
Copper vacuum chamber VC11

Stainless vacuum chamber VC07

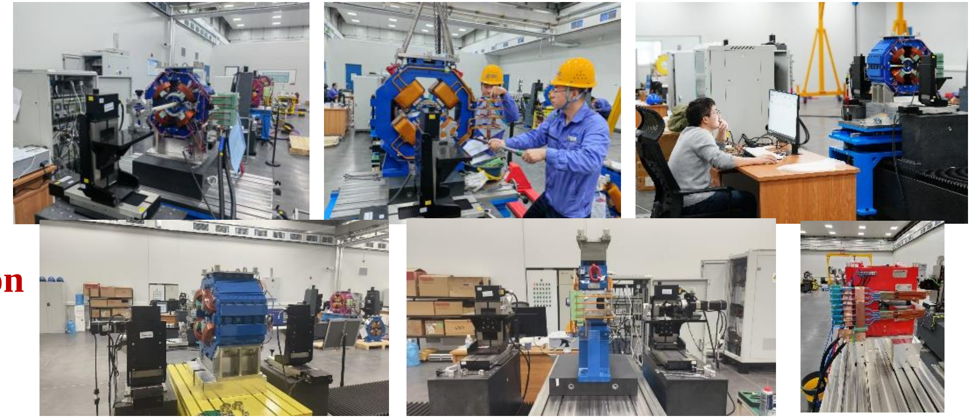
- Solved key issues, including vacuum chamber materials and drawing processes, coating equipment construction and commissioning, VC07 and VC11 section development, etc.

Equipment Offline Commissioning Progress

Construction of high power testing platform for linear accelerator structure has been completed



Magnet offline installation and Commissioning



Installation process verification of the pre-injector section

Equipment pre-alignment

Through the installation of a high-power testing platform and injector sample section, the installation team was adjusted, initial installation specifications were established, and the consistency between the BIM design of the last line of the injector and the installation effect was verified.

Progress of the Construction

Current Status of the Facility Construction

3D rendering

Construction site photo 2025.07.06

Summary

- The upgraded HLS has reached the advanced level of similar facilities in the world
- The preliminary research and development project of HALF has successfully passed the process test and the process acceptance
- In June 2023, the Hefei Advanced Light Source Project was officially launched. HALF is a low-energy fourth generation synchrotron radiation light source based on a diffraction limited storage ring
- At present, HALF’s construction is ongoing, The project is proceeding smoothly according to the plan

Thank You