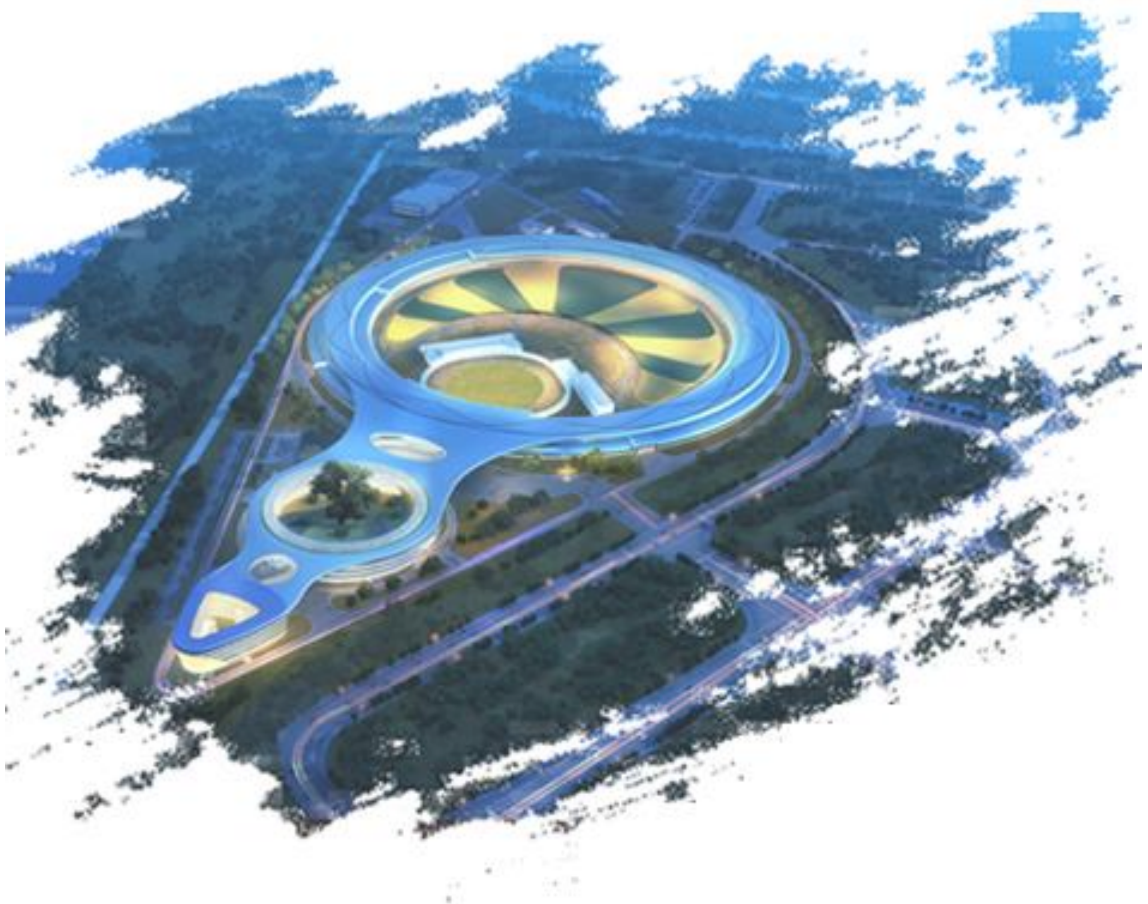
1st high energy synchrotron radiation facility in China

The progress of HEPS project



Ping He
On the behalf of HEPS management

Nov. 08, 2023

12th MEDSI (Nov. 08, 2023)

Outline

Brief Introduction

Synchrotron Radiation Facilities Worldwide

Europe: 16; America: 11; Asia: 21 (Japan: 12); Australia: 1

Introduction

Goals and the target performance of LS (Light Source) storage rings:

Constant delivery of a high quality, intense and stable photon beam to a large number of beamlines

High quality and intense photon beams: Often characterized in terms of

$$Brilliance = \frac{Photons}{Second \cdot mrad^2 \cdot mm^2 \cdot 0.1\%BW} \propto \frac{I}{\varepsilon_x \varepsilon_y}$$

I : Beam current, ε_u : Transverse emittance

Presently a big global wave for 3GLS → DLSR (Diffraction Limited Storage Rings or 4GLS)

Lowering of transverse beam emittance

Optimal ring structure from DBA, TBA lattice → MBA lattice

Ring-Based LS Future Trends

- A global wave today to construct (or *re-construct*) ring-based LSs having the horizontal emittance ε_H by **tens of factors** below the “nm·rad” range

<u>Basic principle used:</u>

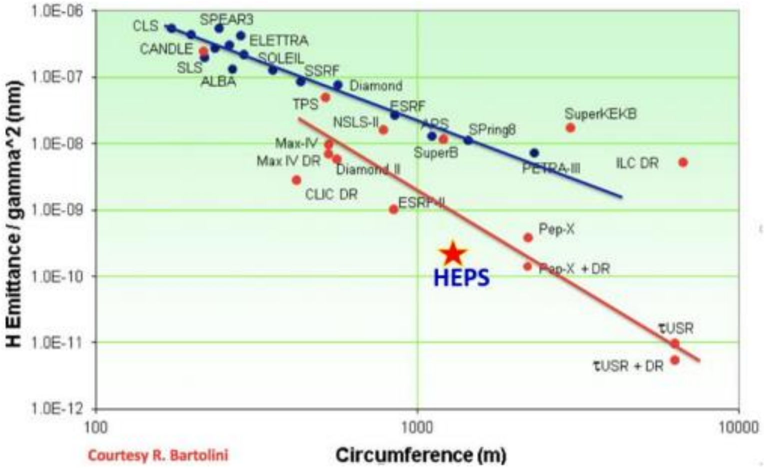
$$(\varepsilon_H)^{Theoretical}_{Minimum} \propto E^2 \cdot \theta^3$$

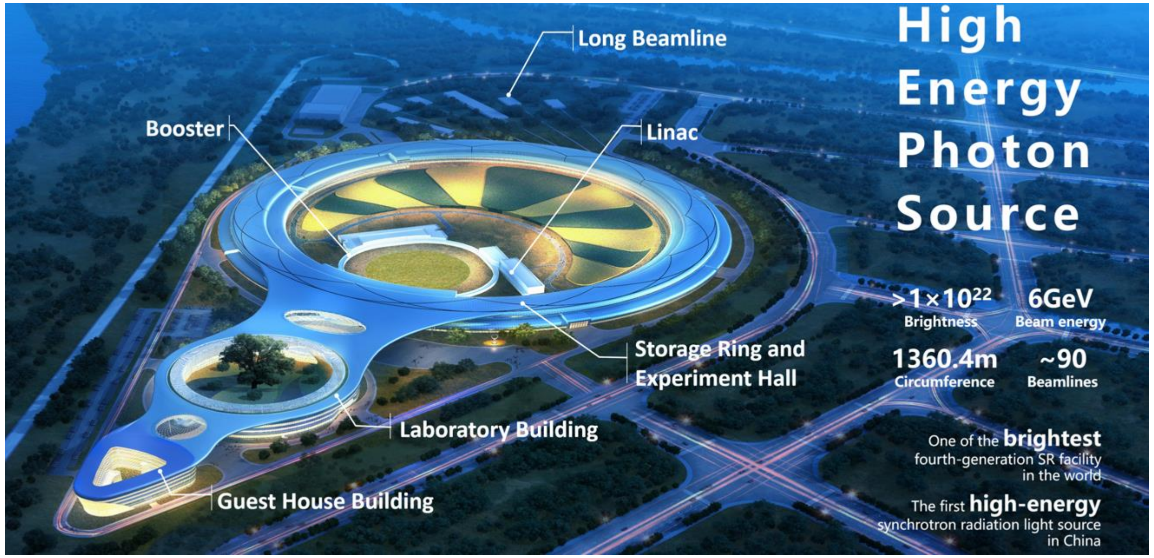
E: Beam energy, θ: Bending angle

Beam energy

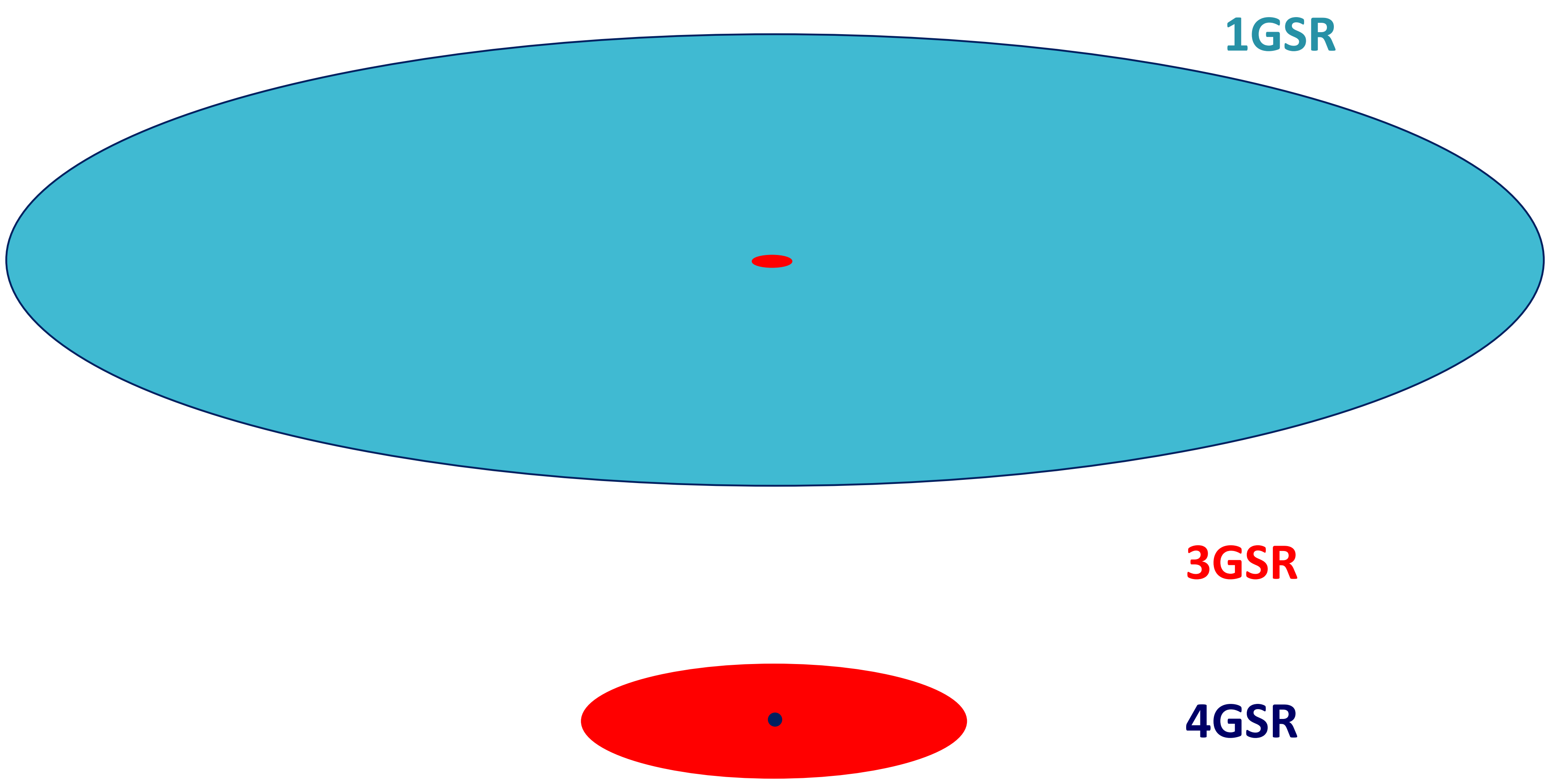
$$\epsilon_0 \sim \frac{E^2}{(N_s M)^3}$$

Number of sectors   Dipoles per sector



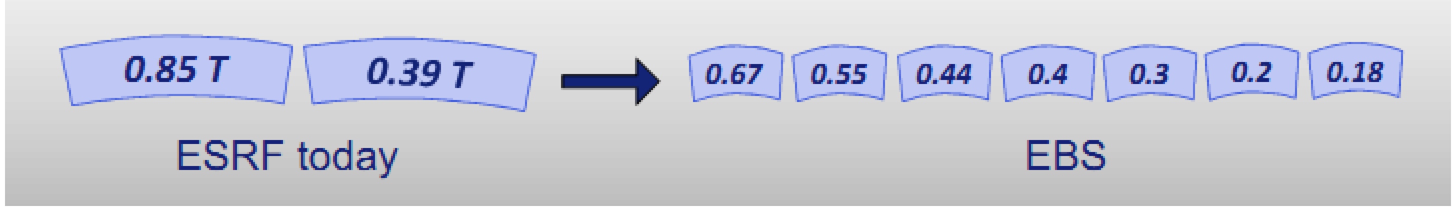


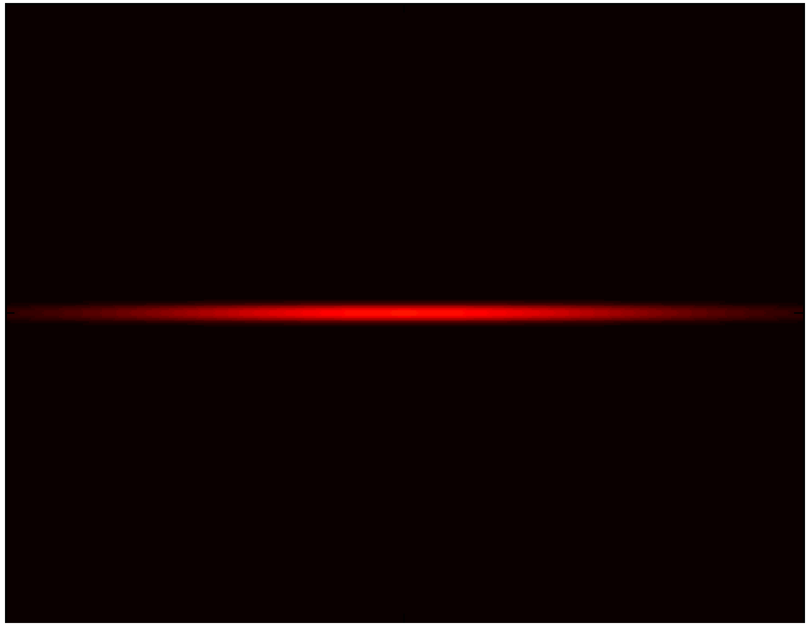
Emittance

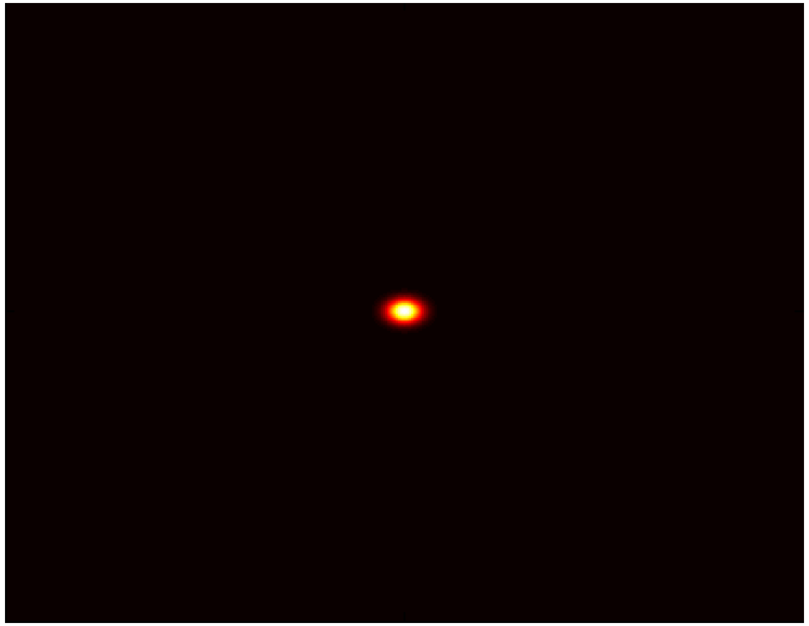


Technology advantage: accelerator

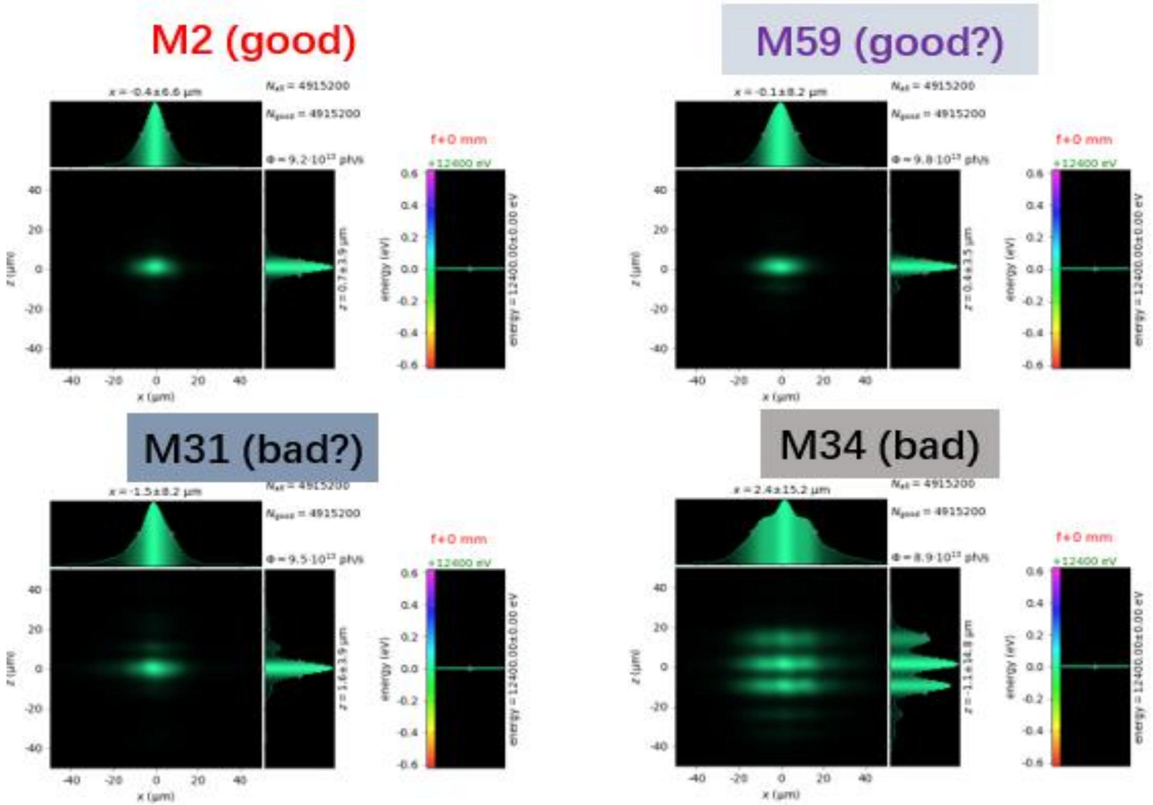
$$\varepsilon \propto \frac{E_e^2}{\left(N_{sect} \cdot N_{dipole}\right)^3}$$







Technology advantage: beamline



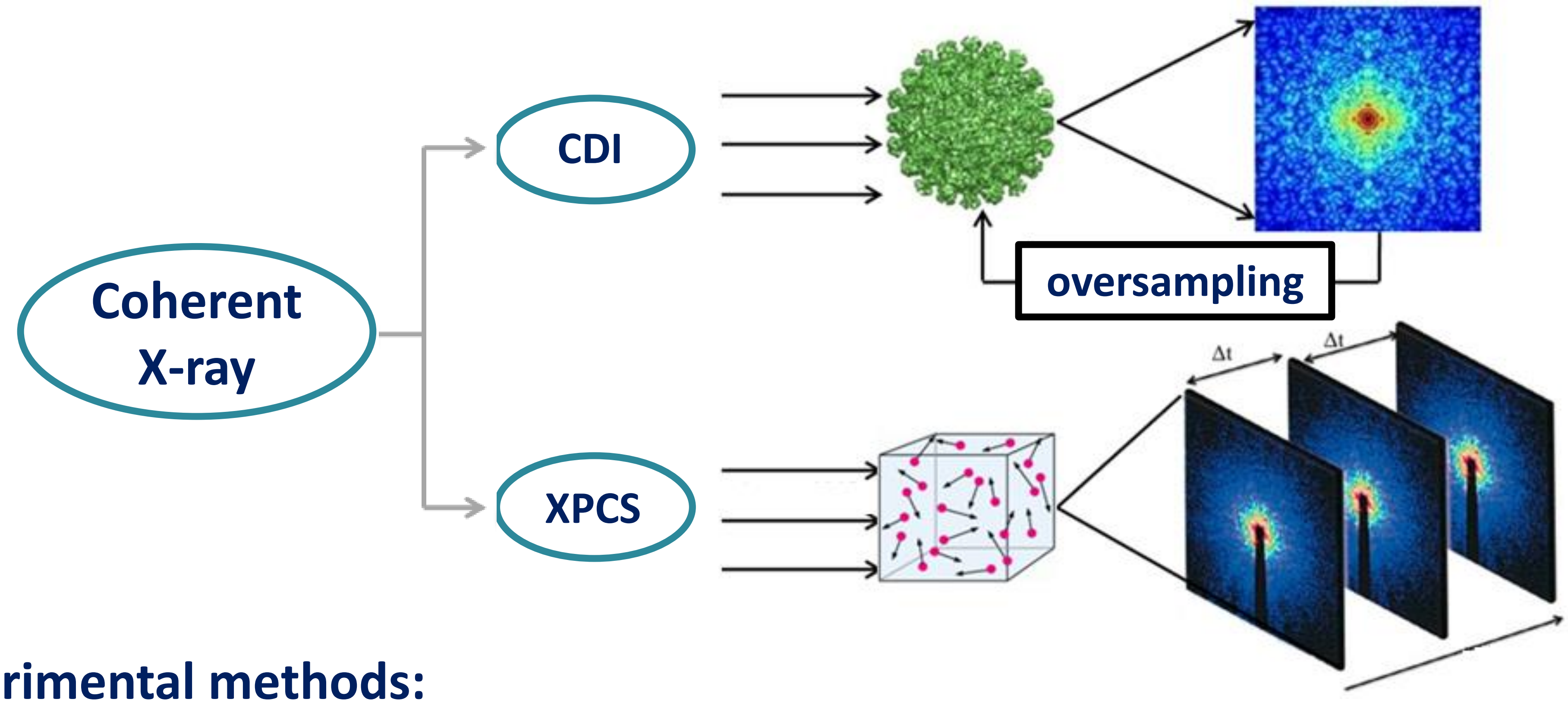
Due to the coherence,

- Coherent optic must be used
- The characterization and metrology of optical components (crystals, mirrors, CRL, etc.) are different, the parameters used before (slope of error, roughness, etc.) are not enough for identify the qualities of optical behaviors
- Extremely high heat-load

We can get:

- Very small beam: nm size
- Very high flux: 2-3 order higher than 3GSR
- Coherent beam

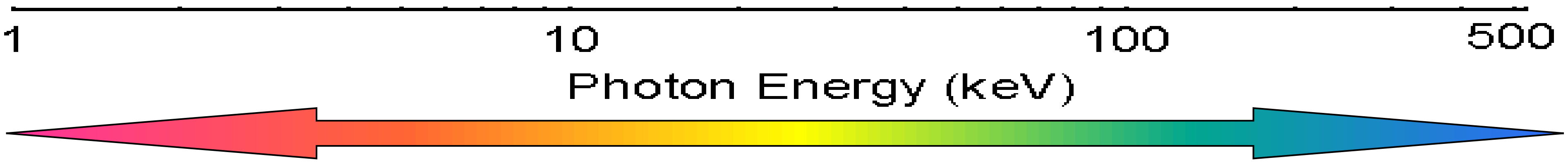
4th generation SR: experiments



New experimental methods:

- Coherent Diffraction Imaging (CDI): non-crystal, nano-crystals (Cells, organelle, nano-catalyst, etc.);
- X-ray Photon Correlation Spectroscopy (XPCS): dynamic properties;
- Nano-probe;
- New methods?

Energy Ranges of Synchrotron Radiation Facilities

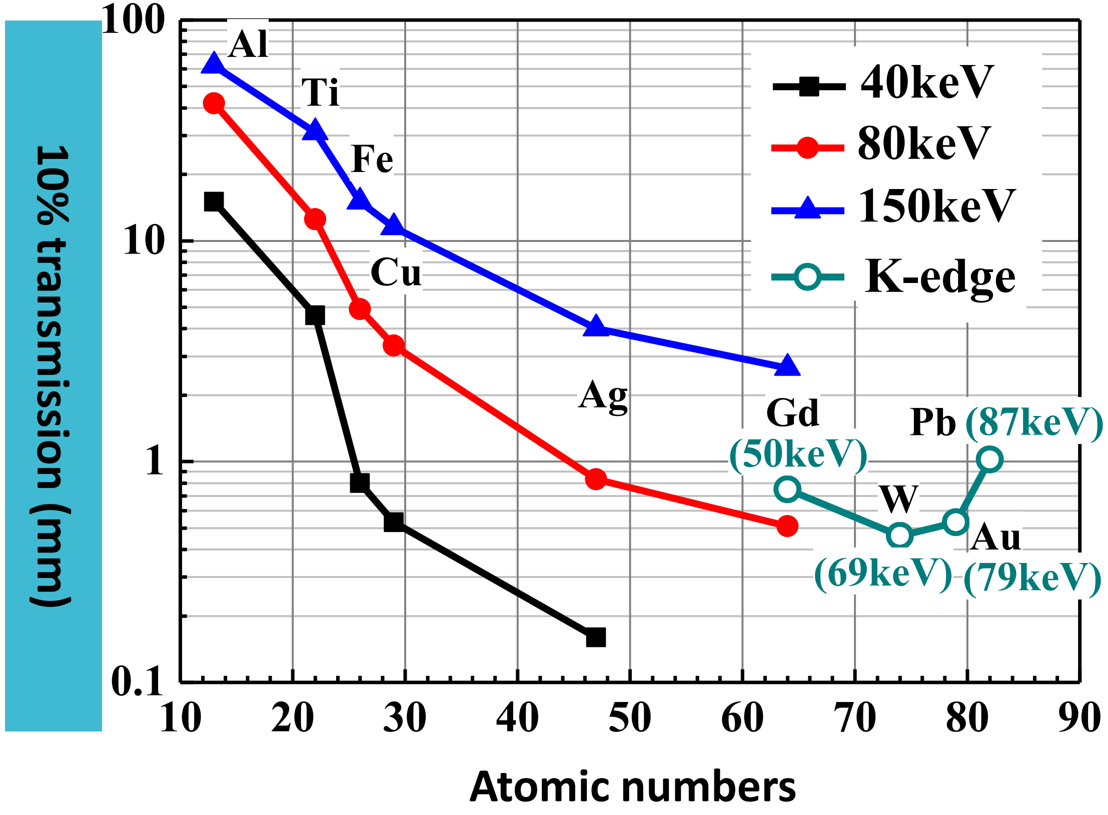


	Low Energy (~1GeV)	Medium (~3GeV)	High Energy (≥5GeV)
Types	**Low Energy (~1GeV)**	**Medium (~3GeV)**	**High Energy (≥5GeV)**
Penetration depth	**nm**	**mm**	**mm-cm**
Samples	**Surface**	**Shallow**	**Real components** **Extreme conditions**

High-energy synchrotron radiation sources are suitable for "real materials under real conditions".

The Penetrative ability of Hard X-ray

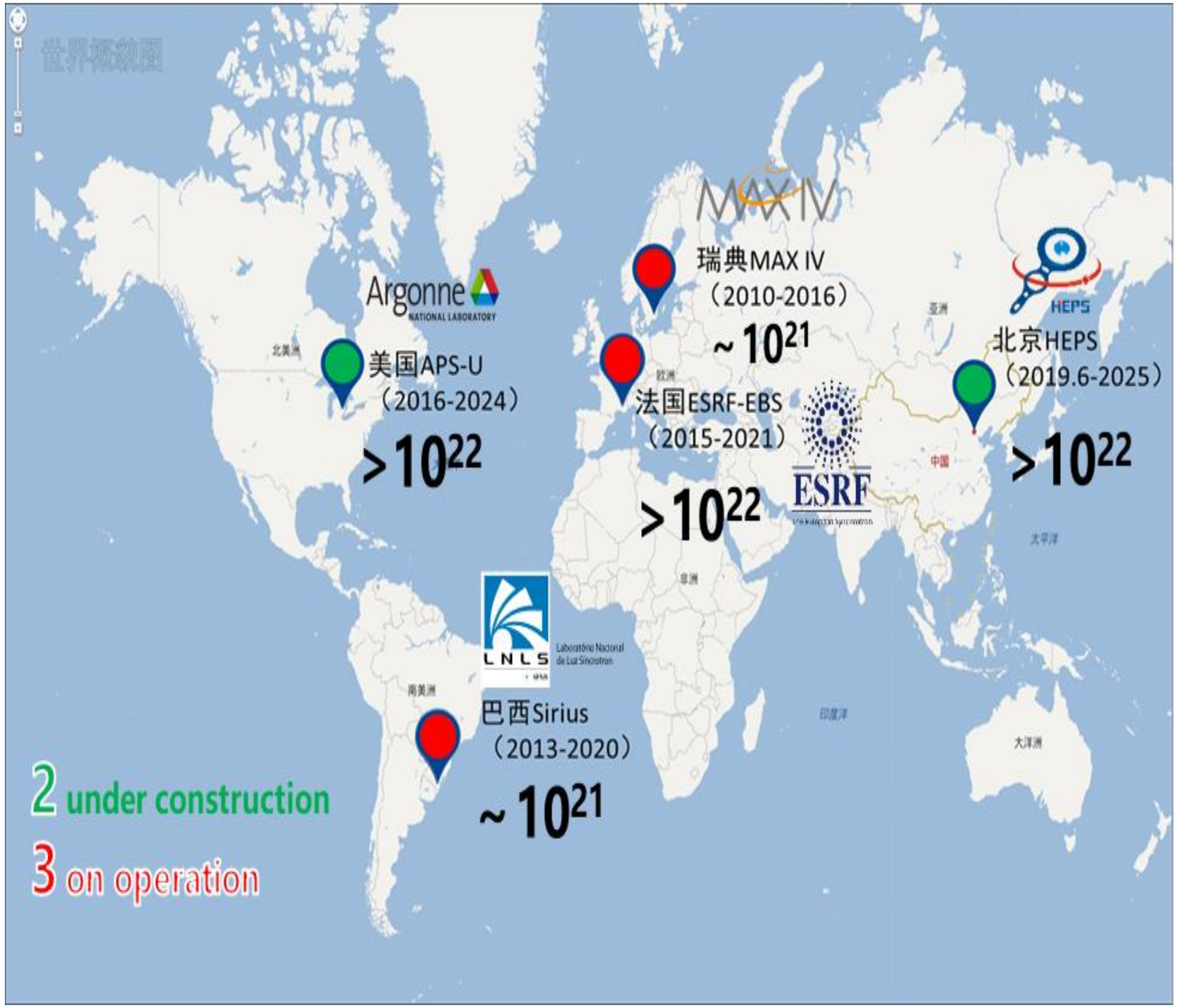
Hard X-ray:
Penetration
Atomic resolution
Real conditions: high/low temperatures, high pressure, high fields, reactive atmospheres



Hard X-ray: Providing better chances for materials studies, especially the materials under conditions.


High Energy Photon Source
Long Beamline
Booster
Linac
Storage Ring and Experiment Hall
Laboratory Building
Guest House Building
>1×10^22 Brightness
6GeV Beam energy
1360.4m Circumference
~90 Beamlines
One of the brightest fourth-generation SR facility in the world
The first high-energy synchrotron radiation light source in China

One of the brightest fourth-generation SR facilities in the world

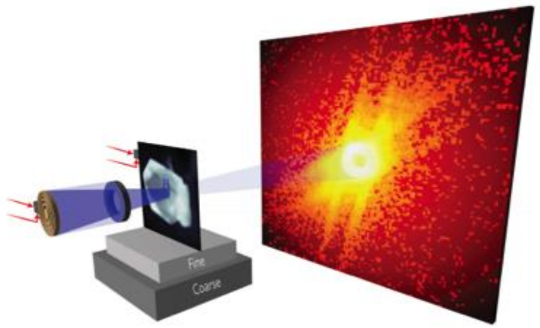


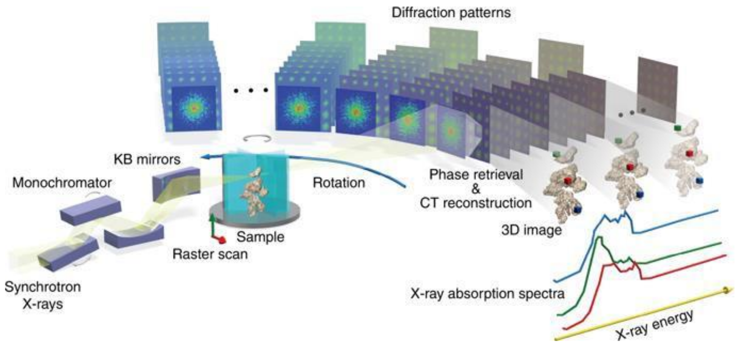
Main parameters	Unit	Design goals of HEPS
Beam energy	GeV	6
Circumference	m	1360.4
Hori. Natural Emittance	pm·rad	< 60
Brightness	phs/s/mm^2/mrad^2/0.1%BW	>1x10^{22}
Beam current	mA	200
Injection		Top-up

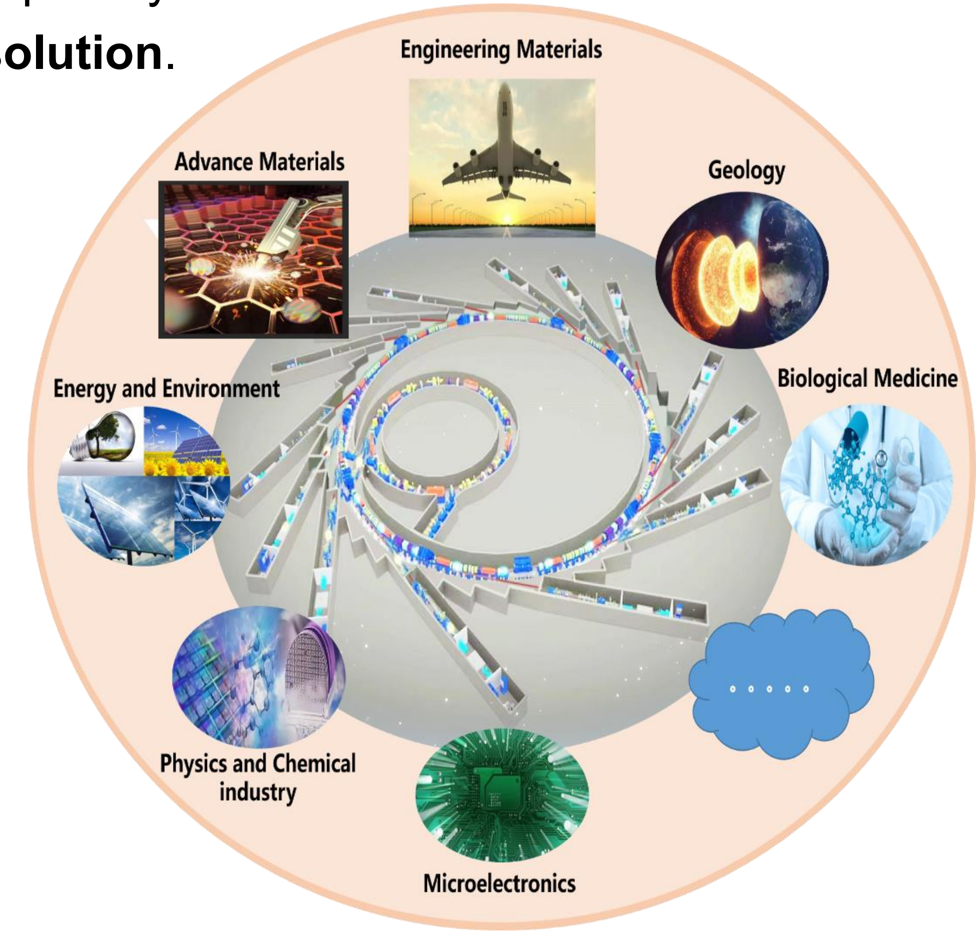
Powerful light sources –
required with widely tunable frequency range from Infrared to X-rays !

HEPS will provide **high-energy, high-brilliance, high-coherence** synchrotron **light with energies up to 300 keV and more**, with the capability for **nm spatial resolution, ps time resolution, and meV energy resolution**.

While providing conventional technical support for the general users, HEPS will operate as a platform to analyze the structures, as well as the evolution of structures of engineering materials in the whole process, by in-situ, multi-dimensional and real-time observation.



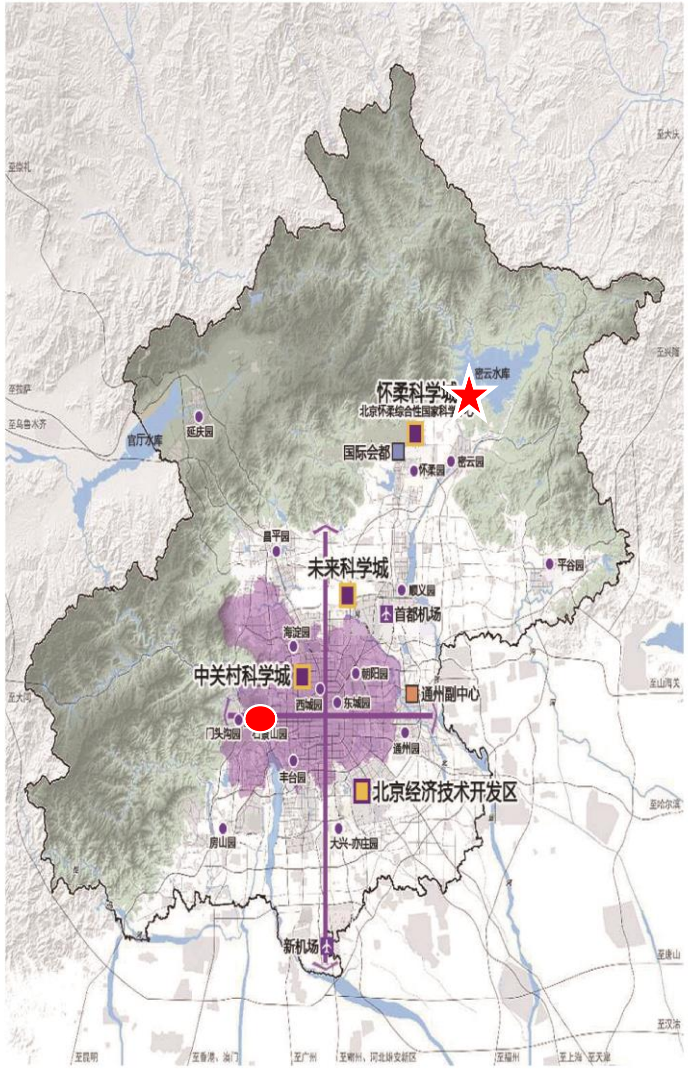




Location

about 80km away from IHEP

- **Huairou Science City** (an area of 233 acres):
  - **Five big science facilities: HEPS,** SECUF (Synergized Extreme Condition User Facility), the Meridian Project Phase II, EarthLab (the Earth System Numerical Simulation Facility), the multi-mode, multi-scale biomedical imaging facility
  - **Series research platforms** in energy, environment, biology, materials, etc.

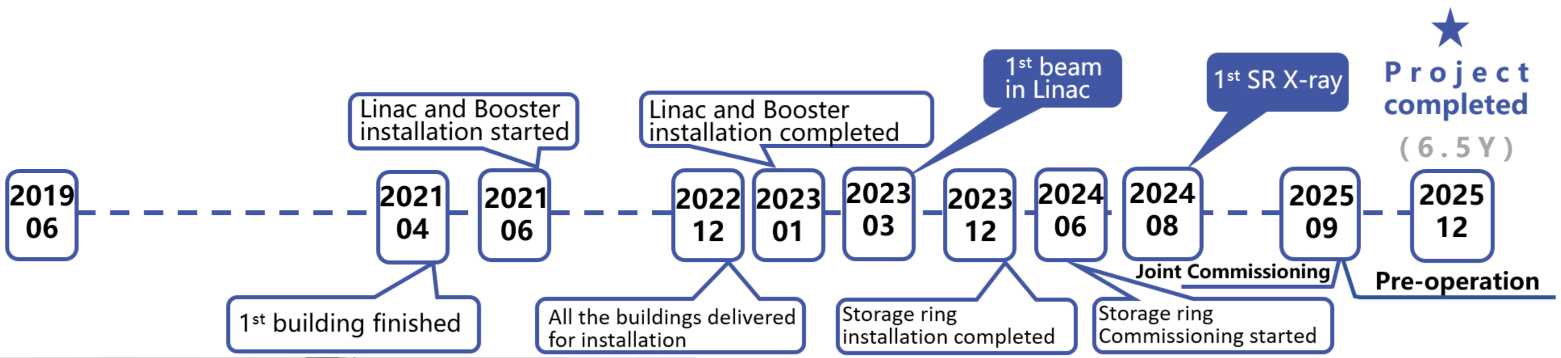


Schedule (2019-2025)

- **The construction period was estimated to be 6.5 years.**

  - Date of Groundbreaking ceremony: Jun. 29, 2019

  - Project is scheduled to be completed in 12.2025

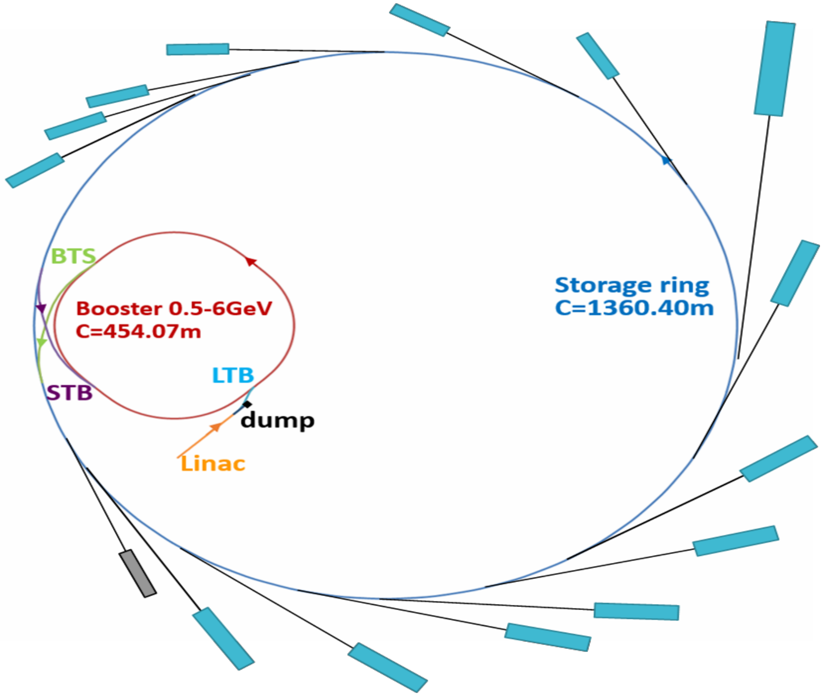


Aug. 8, 2022, the installation in the booster tunnel began.

Jun. 28, 2021, HEPS Installs First Piece of Accelerator Equipment in Linac Tunnel.

Accelerator

By using the 7-Bending Achromatic (7BA) lattice, the horizontal emittance of the electron beam becomes better than 60pm·rad.



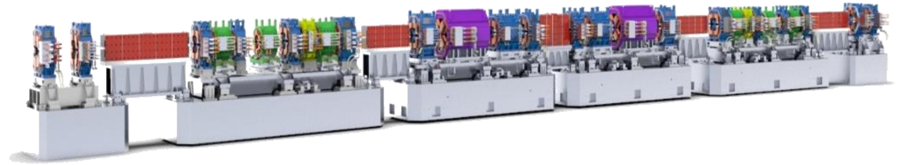
2400+ Magnets

700+ BPMs

~2000 vacuum chambers

Requirements of girder design

Resolution	Transverse	≤5μm
	Vertical	≤5μm
Adjusting range	Horizontal	±5mm
	Vertical	±9mm
Eigen frequency		≥54Hz



14 public beamlines built in phase I

More than **90** high-performance beamlines and stations can be constructed in the experimental hall of HEPS.

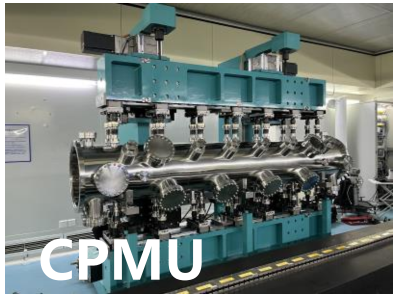
In the first phase, there are **14** public beamlines and stations for users and **1** beamline for optics test.

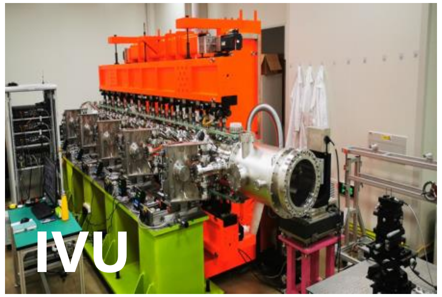
14 ID Beamlines

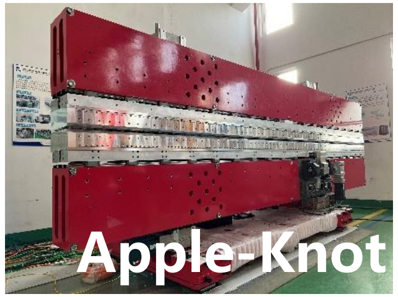
1 BM Beamline

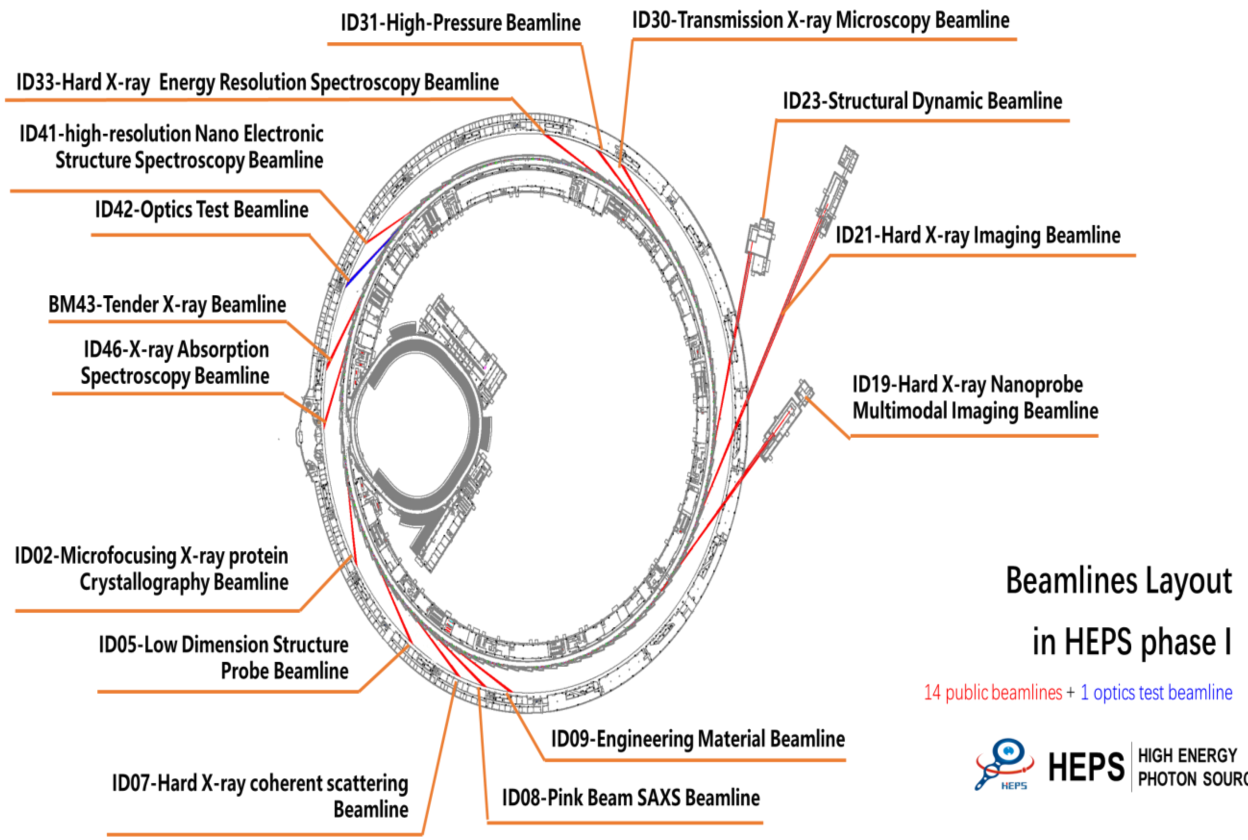
19 Insertion Devices

- **6** CPMU in vacuum
- **5** IVU in vacuum
- **4** IAU in air
- **2** IAW in air
- **1** Mango Wiggler
- **1** Apple-Knot









Main Progresses

Milestones

June 29, 2019
Groundbreaking ceremony

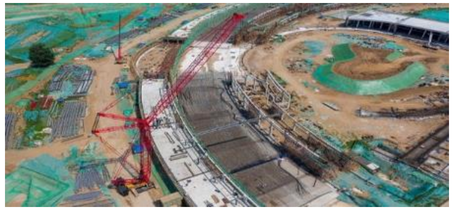
May 12, 2022
The Linac Vacuum-sealing in the tunnel completed

Jan. 13, 2023
The Booster Vacuum-sealing in the tunnel completed

Feb. 1,2023
The first girder was installed in the storage ring tunnel

Mar. 14, 2023
The first electron beam

July 1, 2020
The first steel beam was installed

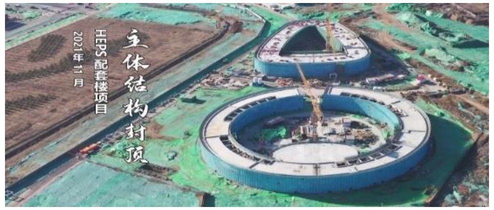


Apr. 13, 2021
Utility installation in NO.2 Hall commenced

June 27, 2021
Roof-sealing work for the main ring building completed

June 28, 2021
HEPS Installs First Piece of Accelerator Equipment in Linac Tunnel.

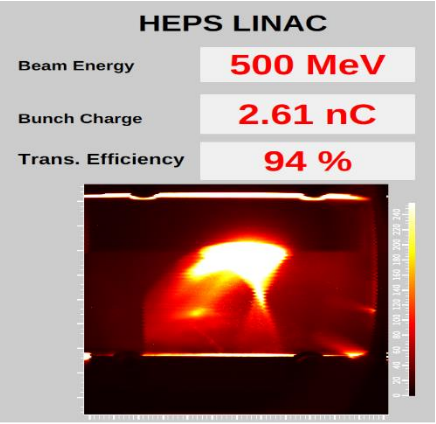
Nov. 18, 2021
Roof-sealing work for ancillary buildings completed



The progress of Accelerator

LINAC

Linac tunnel



The first electron beam of the HEPS was accelerated to 500 MeV with better than 2.5 nC of bunch charge by the Linac on March 14, which was a key milestone of the HEPS project—HEPS beam commissioning had begun.

Milestones of the HEPS Linac

29/06/2019: Design completed

28/06/2021: Electron gun, the first piece of accelerator equipment, was installed in the Linac tunnel.

08/03/2022: Installation in the Linac tunnel begun

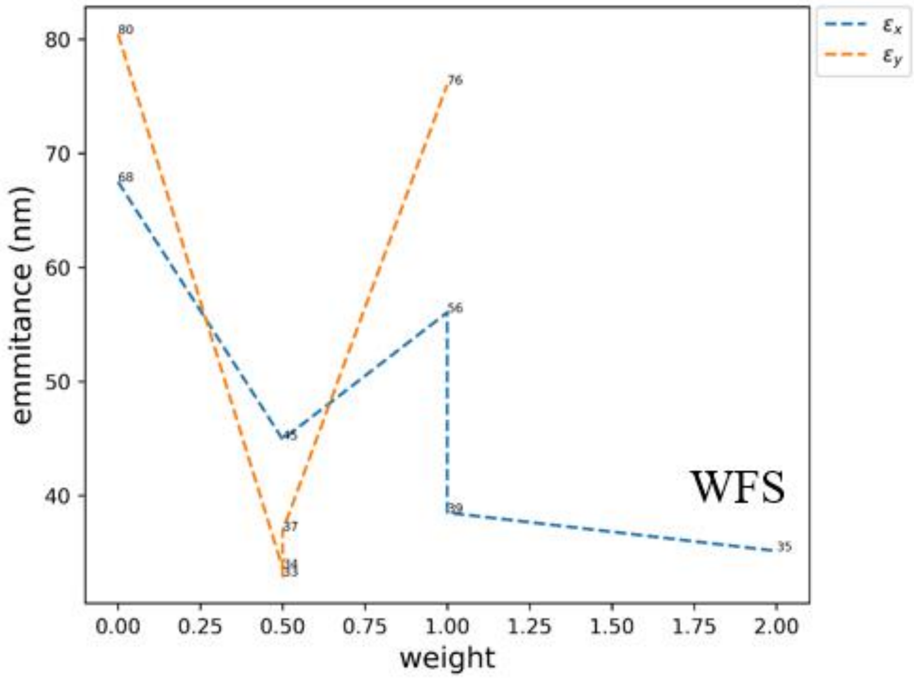
12/05/2022: Linac vacuum-sealing in the tunnel completed

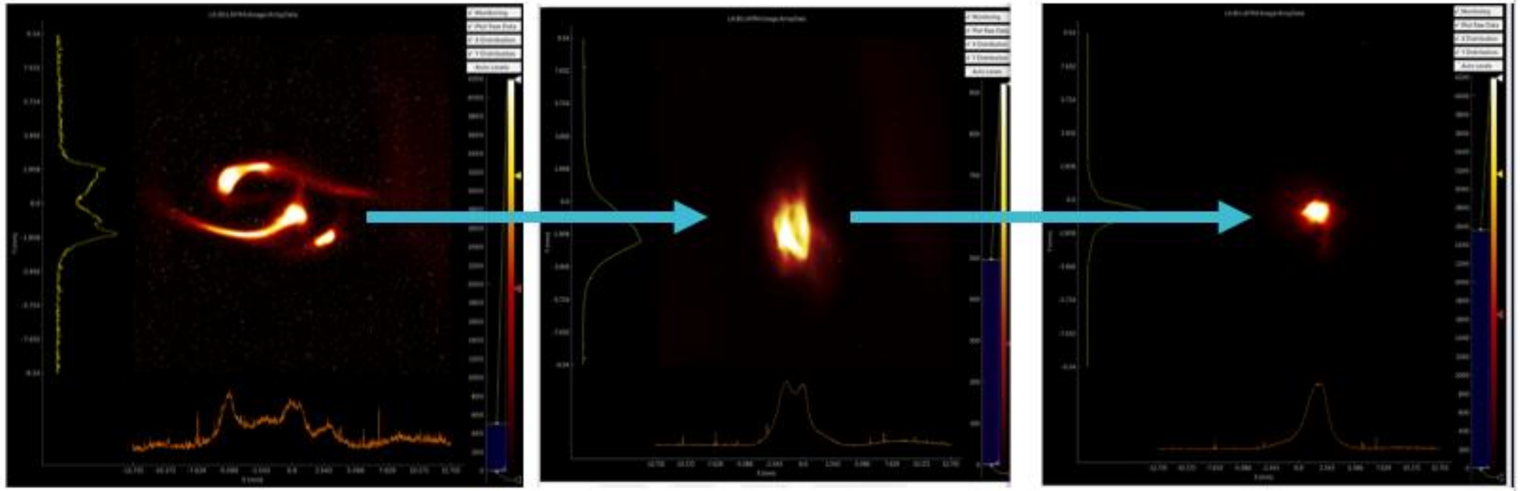
23/09/2022: Linac online RF conditioning completed

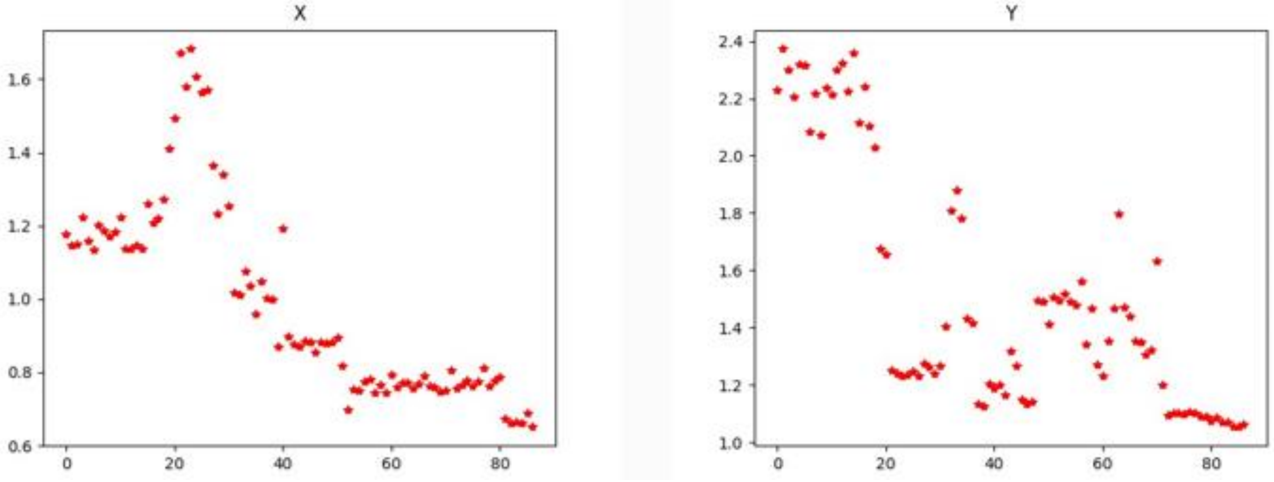
09/03/2023: Linac commissioning began

Emittance optimization: Wakefield

- Beam size optimization
- Wakefield-free steering （WFS）







The progress of Accelerator

RF conditioning started on May 25, 2023 and **the commissioning began on July 25, 2023.**

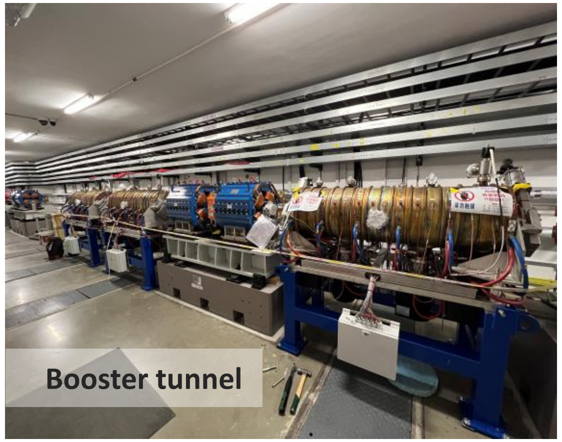
The Booster was vacuum-sealed on Jan. 13, 2023.

Sep. 30, 2022, The pre-alignment of the booster installation cells completed.

Aug. 8, 2022, The installation in the booster tunnel began.

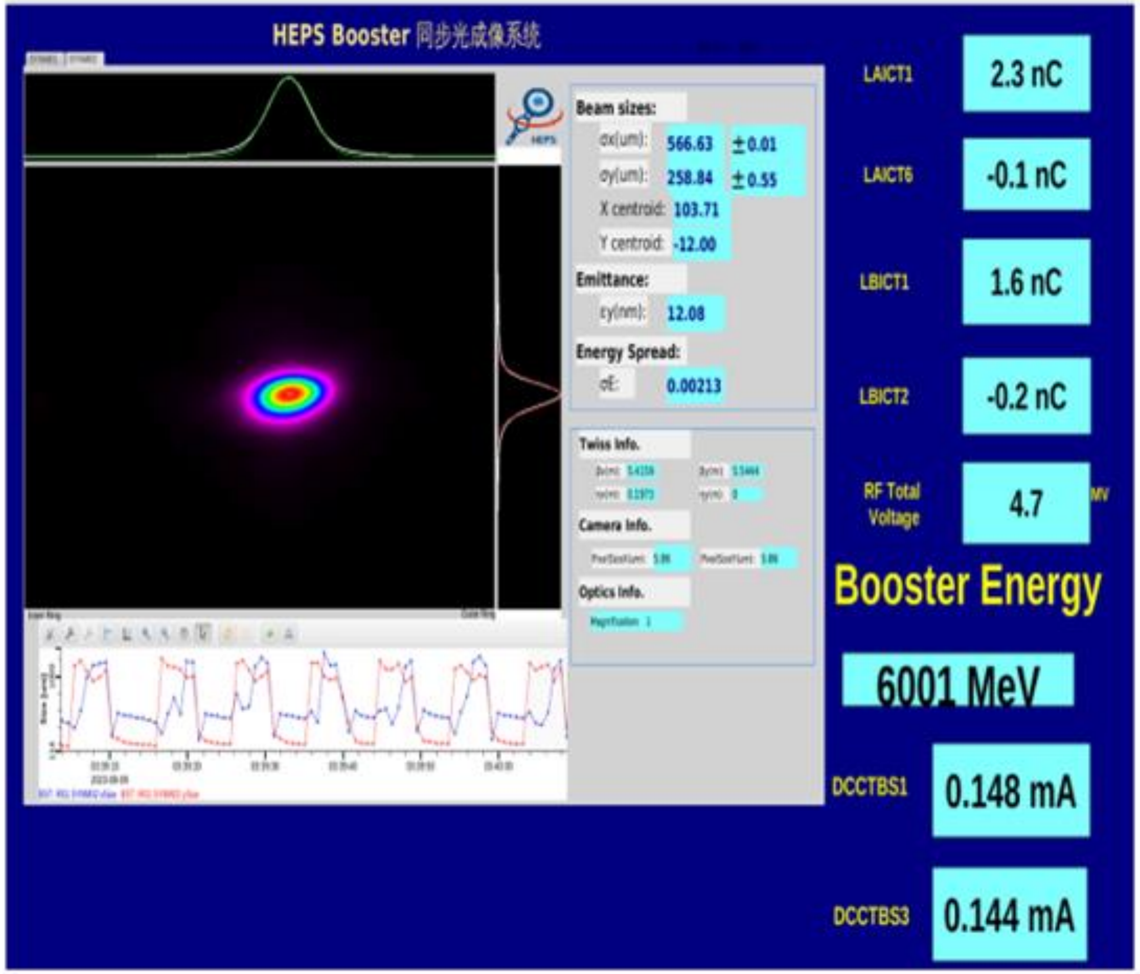
Dec. 14, 2021, Booster tunnel building moved to installation phase.

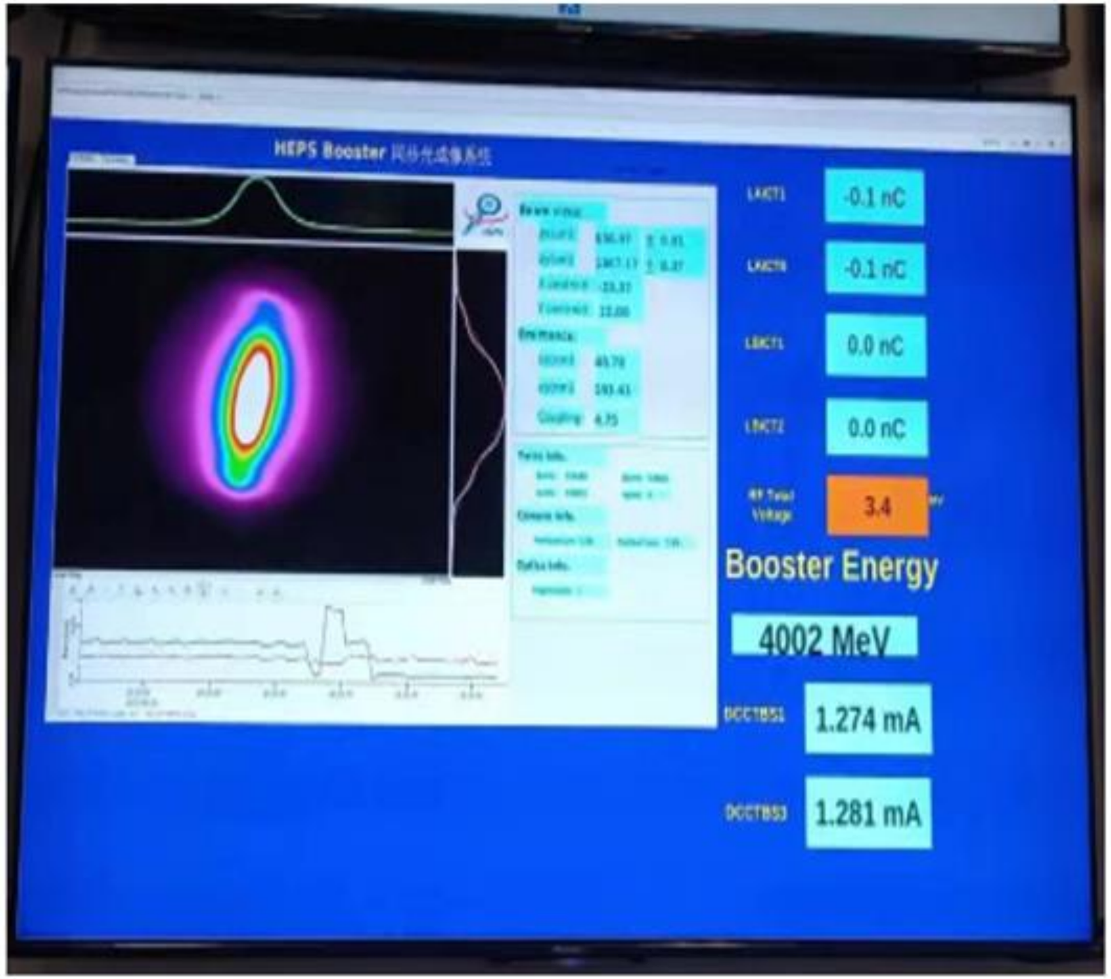
132 pre-alignment cells



Beam energy ramping to 6.0 GeV (with RF)

Booster





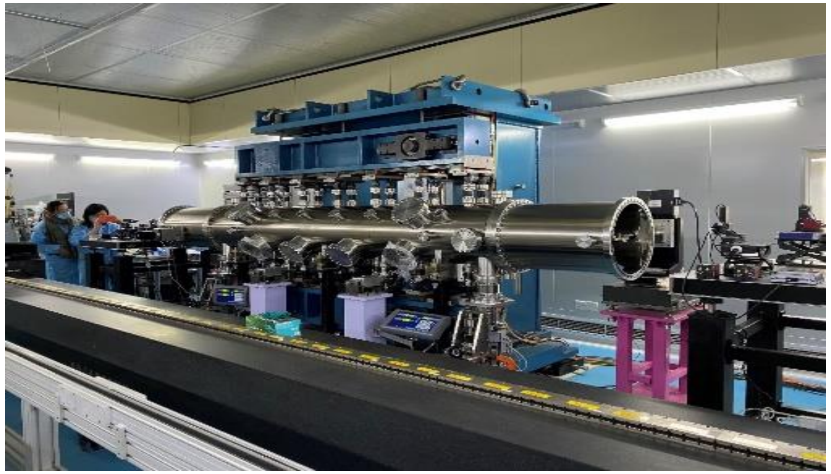
The progress of Accelerator

Storage Ring

1776 magnets **288** girders

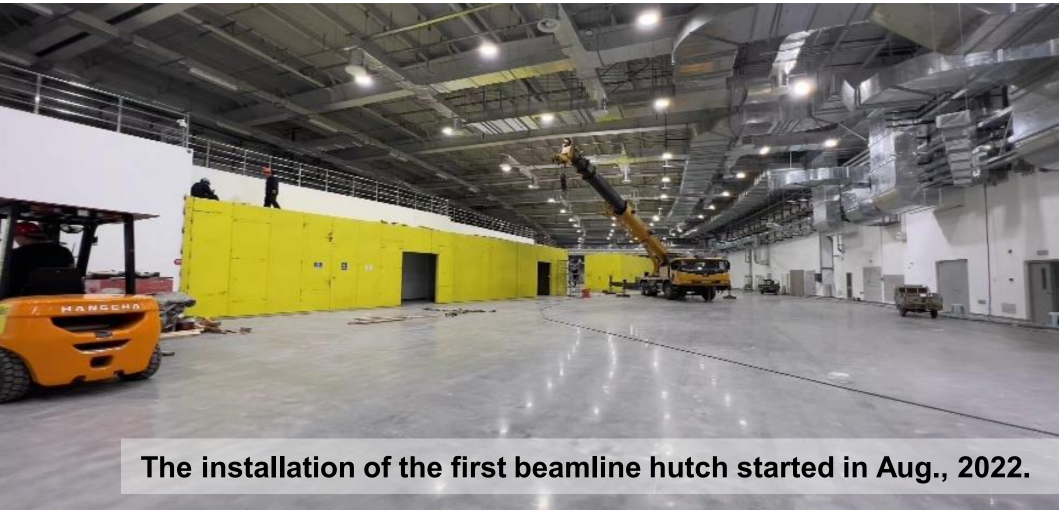
- The installation of a 7BA cell of the storage ring on the experiment bench was successfully finished to optimize process flow.
- The pre-alignment for the storage ring magnet girder began on July 13, 2022.
- The tunnel installation of the storage ring started on Feb. 1, 2023.
- Up to Oct.31, 2023, ~**85%** girders has been installed.

The progress of Accelerator



19 insertion devices (including IAU, IAW, CPMU and IVU) were manufactured and received and all the front-end devices for **12** undulator beamlines installed.

The progress of beamline



The installation of **9** beamline hutches were underway.

The installation of five hutches (XAS, TEX, MX, TXM, XBD beamlines) completed.

The installation of the first beamline hutch started in Aug., 2022.

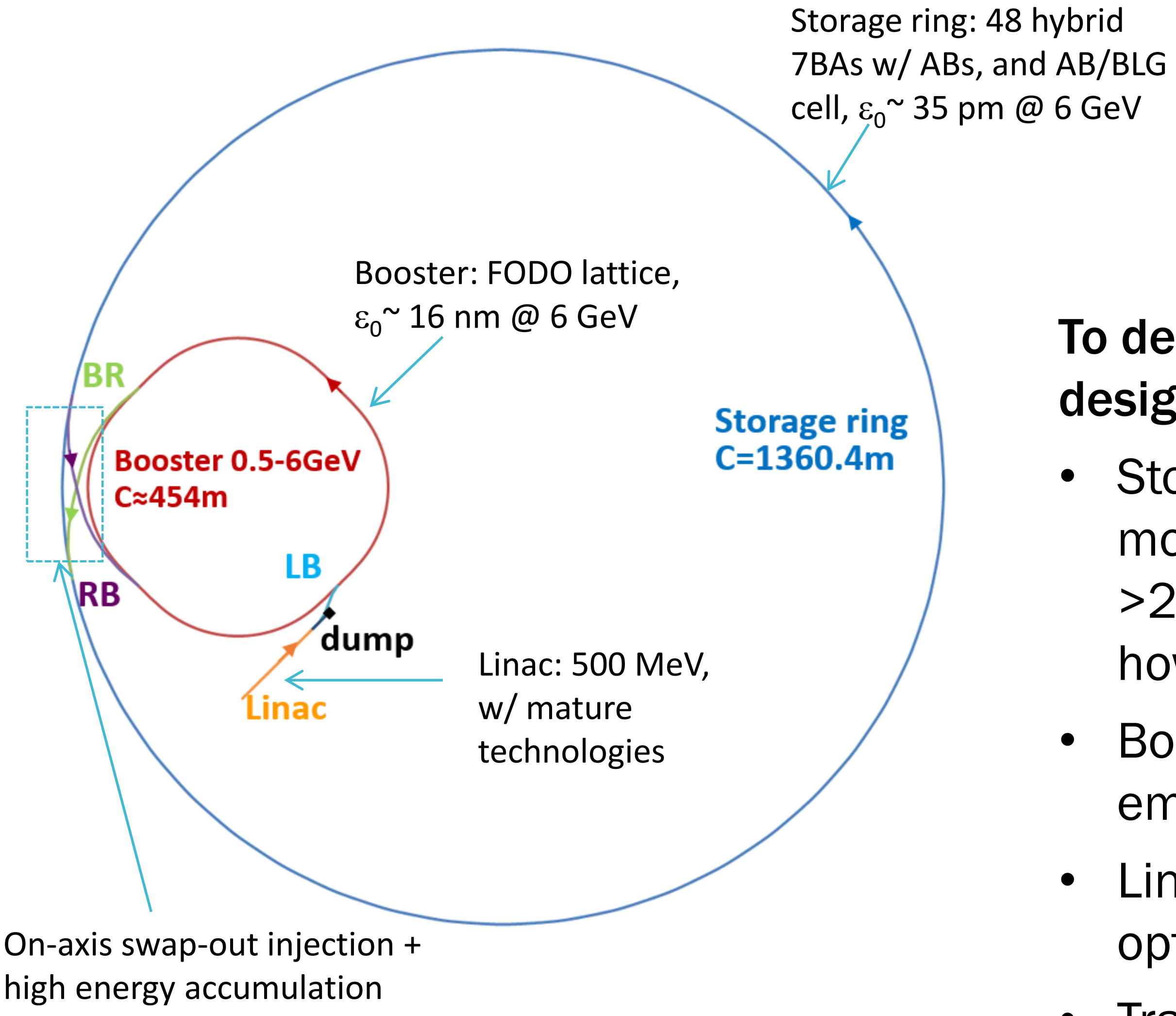
The progress of Utilities

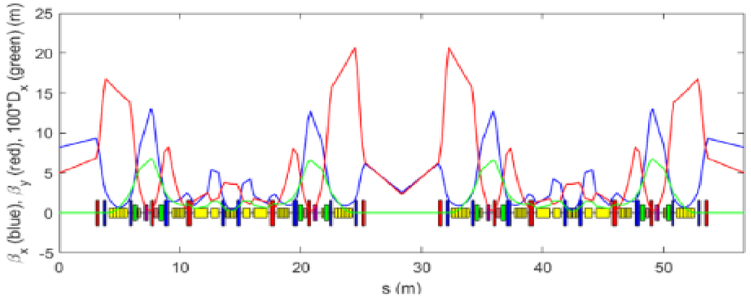
- **85%** of the utility installation had been completed.
- All four switching stations and eleven 10 kV electric power distribution substations were put into operation.

Accelerator

1. Linac, Booster, Storage Ring
2. Accelerator Physics, Magnet, Power Supply, Vacuum, Mechanical, Insertion Device, RF, Cryogenics, Microwave, Linac Power Source, Injection&Extraction, Alignment

Accelerator Physics

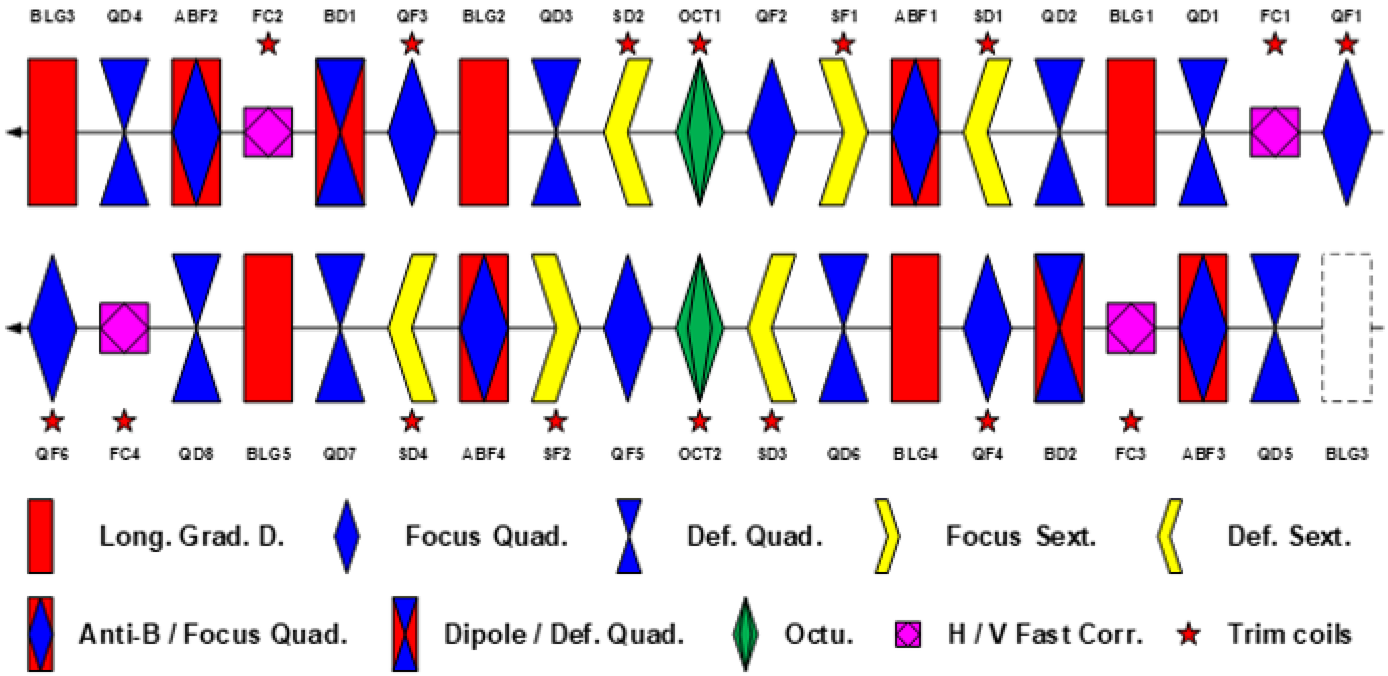




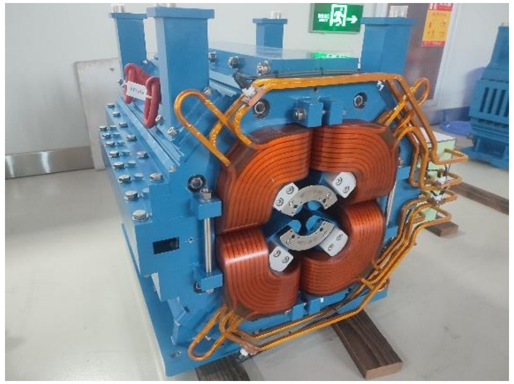
To deal with challenges from technical and engineering design, the accelerator physics design was updated

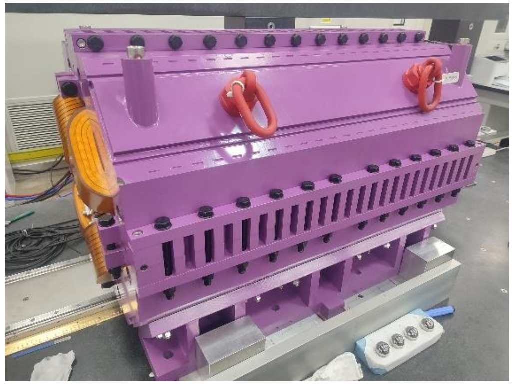
- Storage ring lattice: enlarged drift space in arc (1.1 m more space/7BA), slightly larger magnet aperture (25->26 mm), emittance preserved (34.2->34.8 pm) with however smaller dynamic acceptance
- Booster design: higher bunch charge (2->5 nC), and emittance reduced by more than 50% (35->16 nm)
- Linac design: higher bunch charge (5->7 nC) and optimized layout
- Transfer lines: updated accordingly

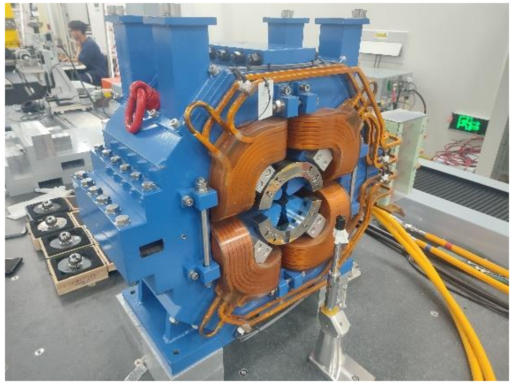
- Magnets
  - 37 magnets in one 7BA cell
  - BLG 0.11 – 1 T
  - Quad 82 T/m
  - BD 66 T/m
  - Sext 6082 T/m²
  - Oct 512600 T/m³
  - Fast Corr 0.08 T




BLG2


ABF2/3


BD1/2


QD4

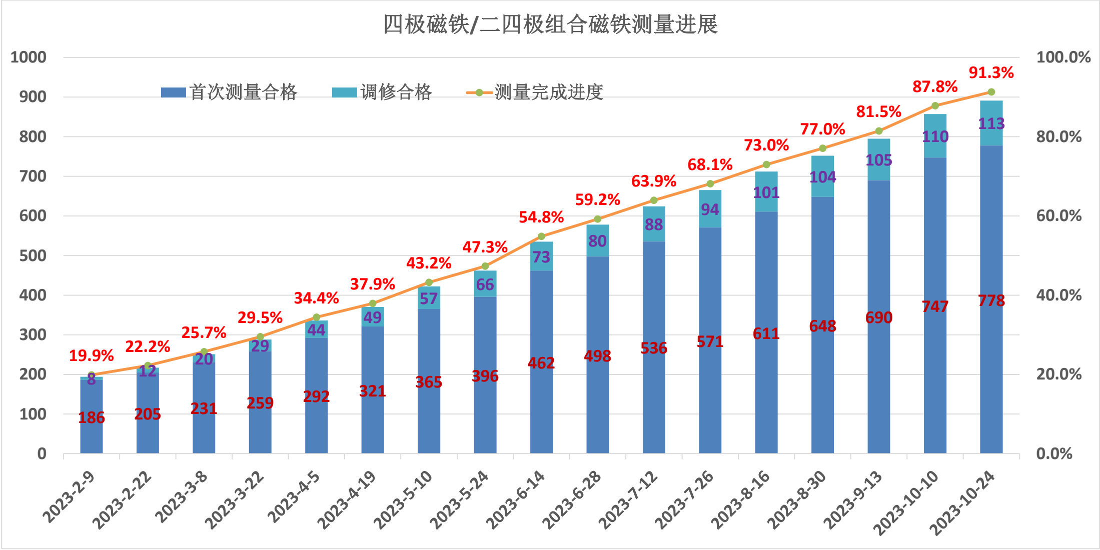
Magnetic field measurement

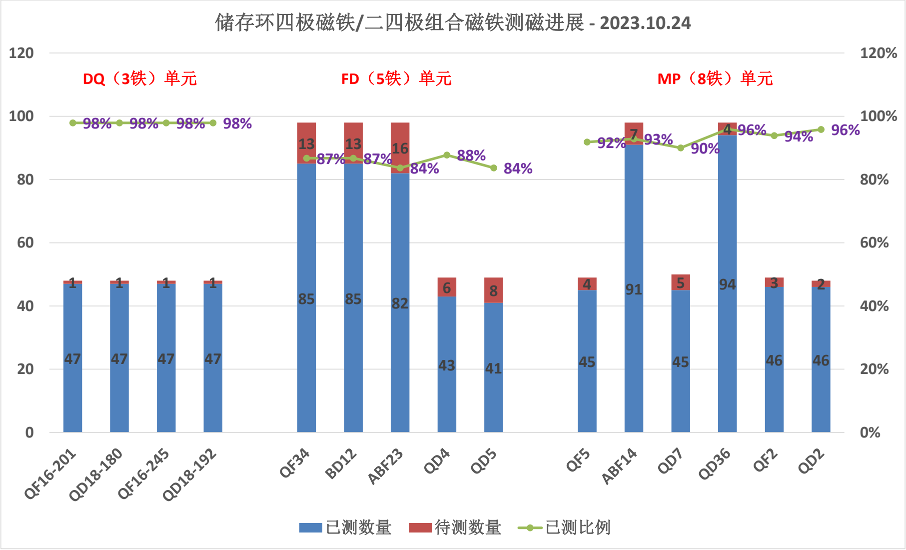
- **Measurement and pre-alignment move on schedule**

- Measurement of the dipoles, quadrupoles and dipole/quadrupole combined function magnet will be finished by the end of November

- All sextupoles, octupoles and fast correctors have been measured

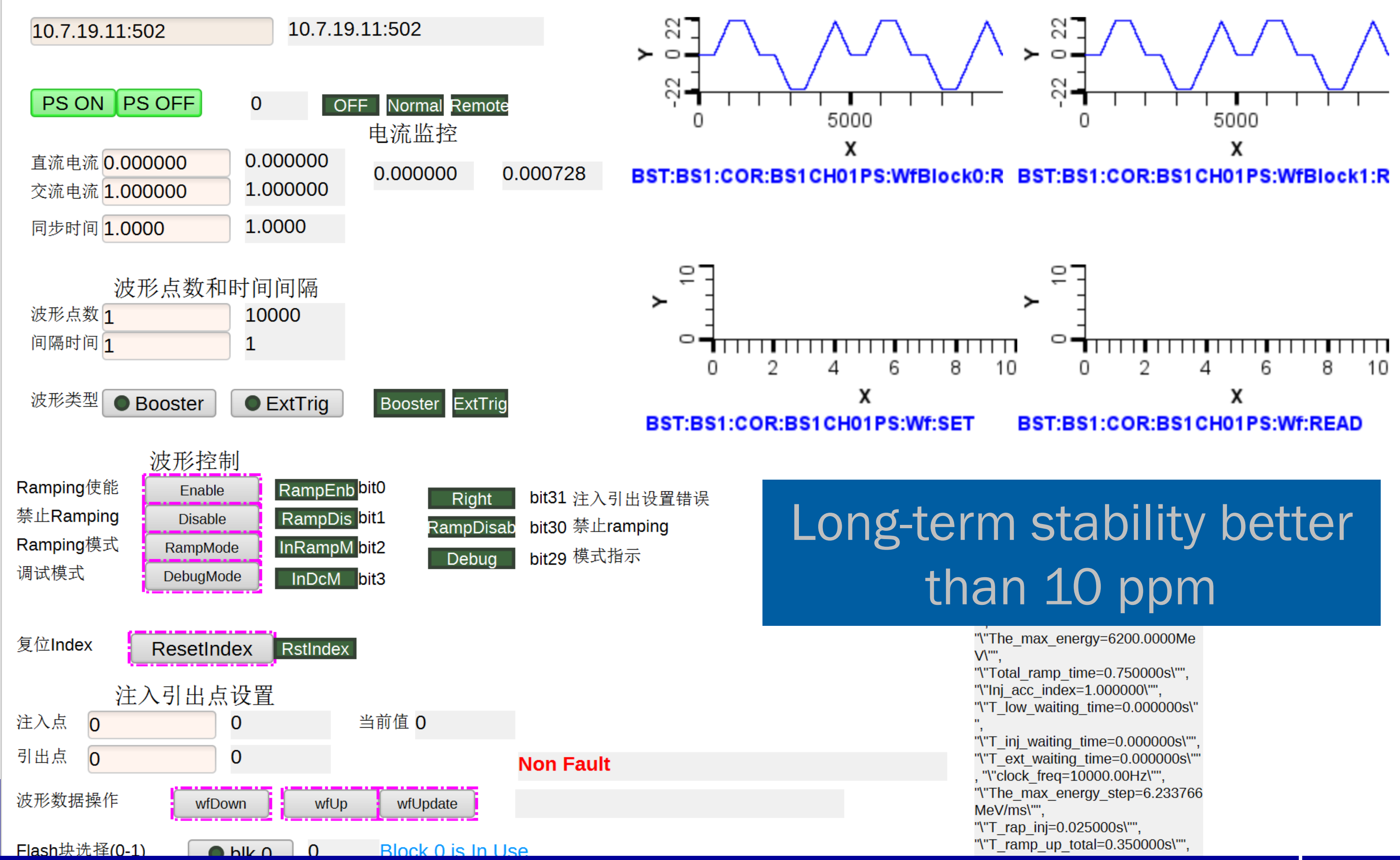
- Fine tuning of the BLGs field integrals is performed by using adjustable screw. All the BLGs are within 5×10^{-5} after tuning





Magnet power supply

- All power supplies installed （total number 2804） at 10 PS Halls and M01-48
- PS for Linac, Low energy transport and Booster started commissioning

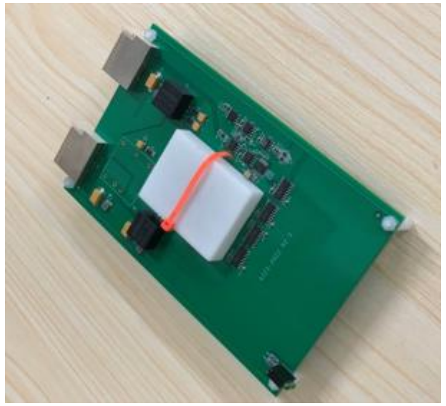


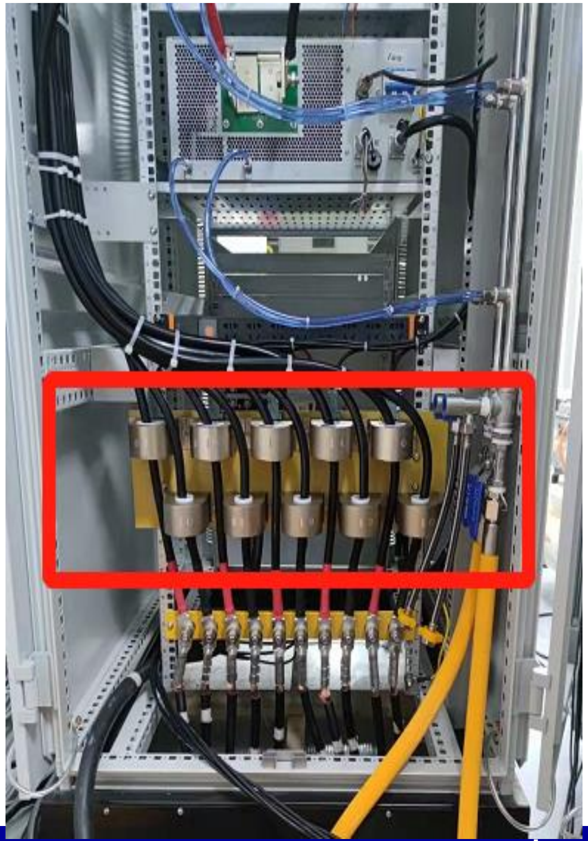
Long-term stability better than 10 ppm

Magnet power supply

- All power supplies are digital-controlled with self-designed DPSCM(Digital Power Supply Control Module) and DCCT(two scales with 20A and 300A).

DCCT: DC Current Transformer (Accuracy < 2 ppm)

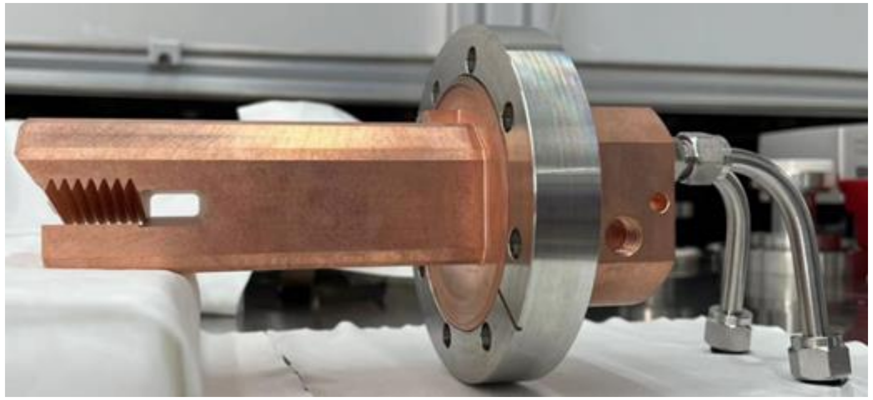



Storage-ring vacuum

- The vacuum components in the storage ring are being mass-produced, and the vacuum equipment of a standard arc cell have been installed and verified

Stainless steel chamber with pumps, photon absorbers and end mask, and copper is coated inside.

Extruded Cu-Cr-Zr (C18150) antechamber



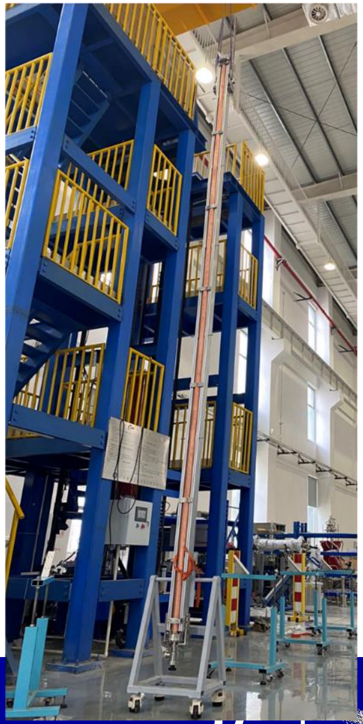
Cu-Cr-Zr /dispersion-Cu crotch photon absorber

RF shielding bellows with double-fingers type, and BPM module is integrated.

NEG coating facilities

- 3 sets of NEG coating equipment have been built
  - 1 for coating small aperture circle vacuum chambers, and 6*3.5m vacuum chambers can be coated simultaneously
  - 1 for antechambers paralleled with 4 groups in a length of 1.5m, and the NEG coating have been verified in a slit height of 6mm with a length of 1.2m
  - A 6m long vacuum chamber can be coated in the 3rd setup by moving solenoid vertically.

NEG coating pumping speed ~ 0.72 L/(s·cm^2)(H2)



Girder & Magnet support

SR magnet support system

- Prototypes developed and engineering design scheme finalized
- Contradiction between the precise motion and stability compromised effectively

  - Eigen frequency： ≥71Hz
  - Motion resolution : 1μm

- Concrete plinths grouting finished in tunnel and passed the final test acceptance.
- Girder mass production finished and installation is in progress, 70% completed.

LA & BS mechanical support

- All the mass production and tunnel installation have been completed

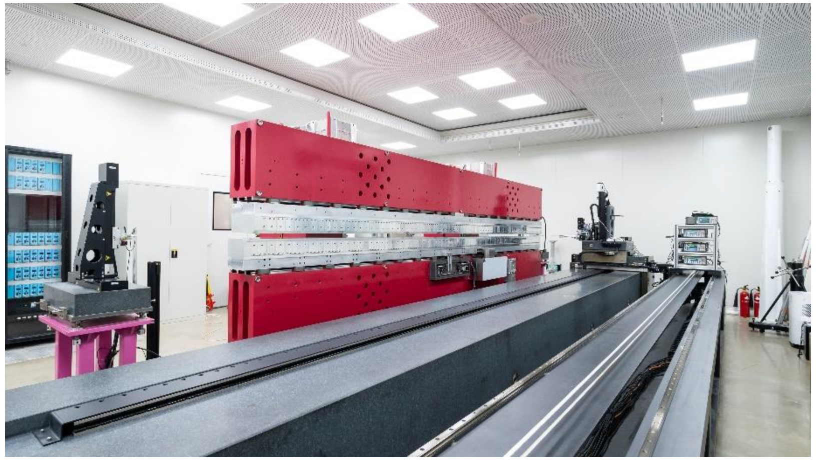
Insertion Device

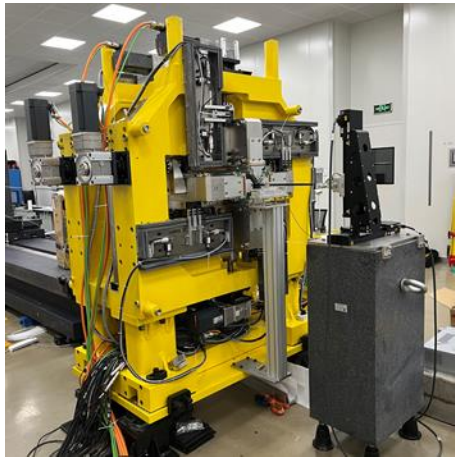
In-air IDs

- The **APPLE-Knot undulator** is an innovative device which can achieve both circular polarization and low on-axis heat load. The "**Mango**" wiggler is designed to offer a big radiation spot size for Large - field X-ray diagnosis and flaw detection. They are both successfully realized and through expert review.
- The development of 6 in-air IDs (4 **IAU**s+ 2 **IAW**s) is finished, ready for tunnel installation.

Merged APPLE-Knot: 1st 4 Array AK

Mango: Scan range 0.6mrad*0.6mrad


AK


MANGO


IAU

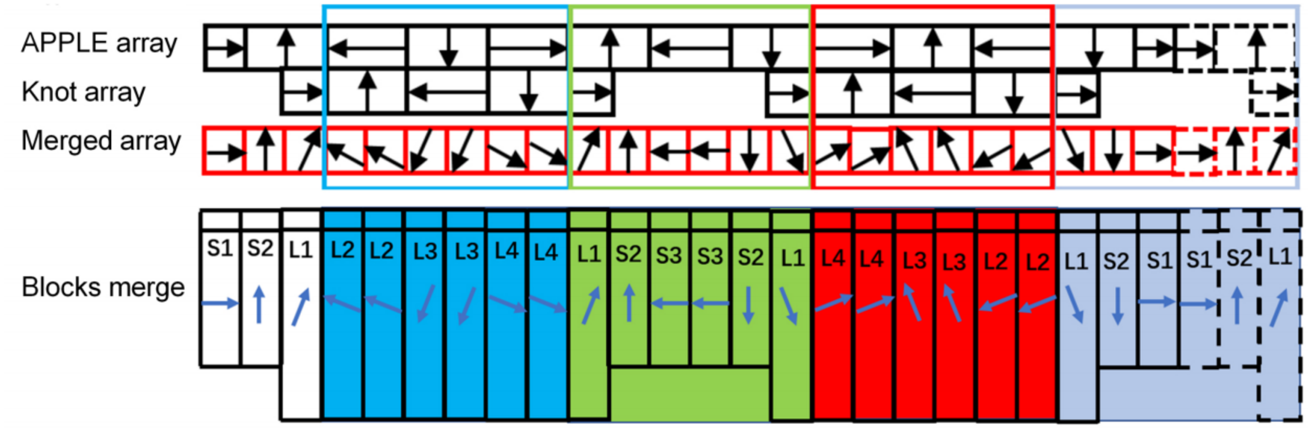

IAW

APPLE-Knot undulator

- ➢The APPLE-Knot undulator is an innovative device which can achieve both circular polarization and low on-axis heat load.
- ➢ Comparing with other AKs, Merged AK has four magnet arrays which have stronger knot field to decrease on-axis heat load further and the drop of vertical polarization degree is declined as well , but engineering challenges arise.

Design parameters of the merged APPLE–Knot undulator.

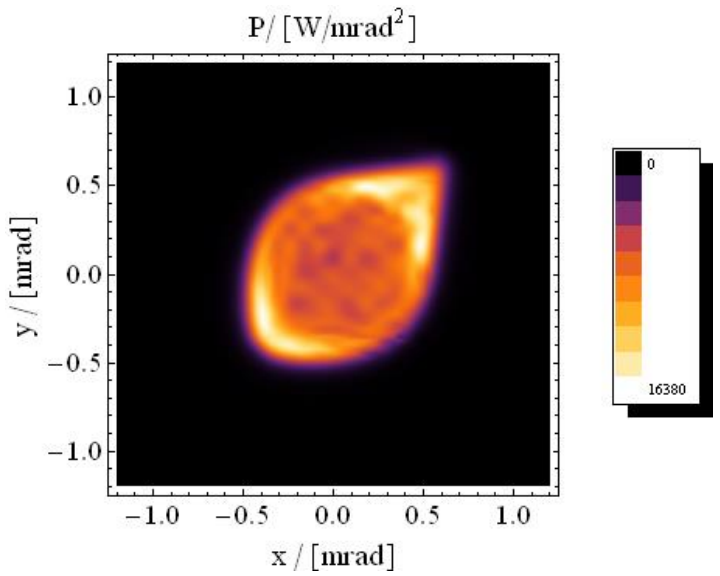
Period length $3\lambda_u$ (mm)	256.8
Corresponding APPLE magnets period length λ_u (mm)	85.6
Corresponding Knot magnets period length 1.5 λ_u (mm)	128.4
Number of periods	18
Dimension of blocks merged by APPLE and Knot magnets (mm)	55 × 55 × 10.7
Dimension of blocks corresponding to blank segments (mm)	55 × 30 × 10.7
The ratio of the magnitudes of magnetization between the APPLE and Knot components	2:1
Clearance between arrays (mm)	1
Gap in horizontal mode @100–2000 eV (mm)	16.60-67.50
Array 1/3 shift in horizontal mode @100 eV (mm)	0/0
Gap in vertical mode @100–2000 eV (mm)	13.80-60.90
Array 1/3 shift in vertical mode @ 100 eV (mm)	42.8 (λ_u/2) / −42.8 (-λ_u/2)
Gap in circular mode @ 100–2000 eV (mm)	15.00-58.00
Array 1/3 shift in circular mode @ 100 eV (mm)	64.2 (3 λ_u/4) / −21.4 (- λ_u/4)

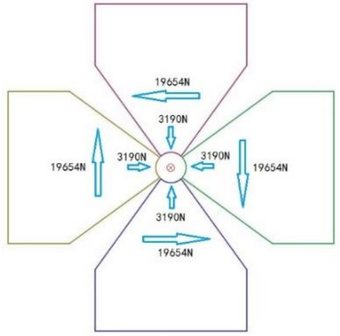


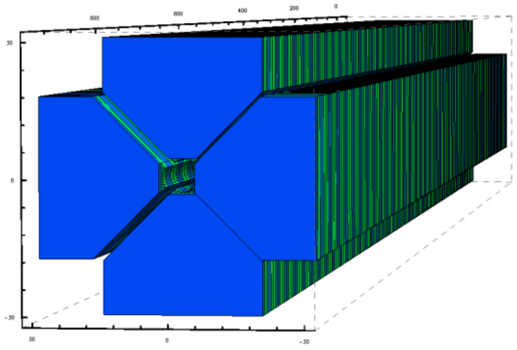
Mango: A new type Wiggler for Large FOV Imaging

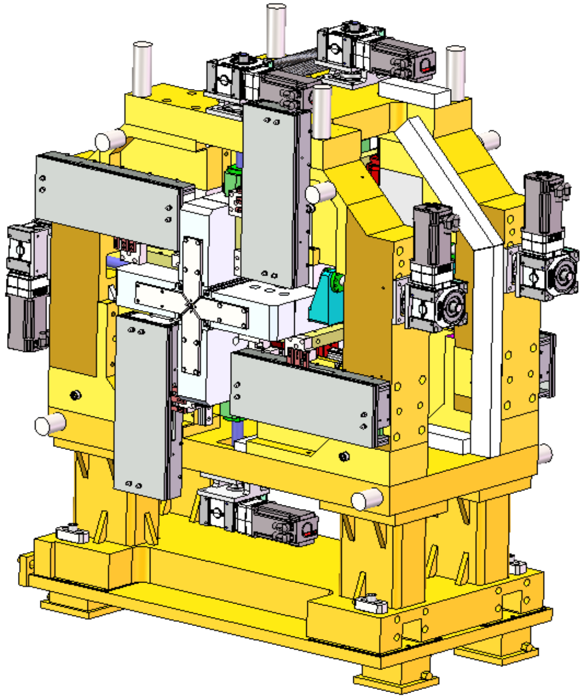
- The "mango" wiggler is proposed by HEPS colleagues in which the shape of the photon beam image is like a mango.
- The big radiation spot size of mango wiggler has special advantages for Large -field X-ray diagnosis and flaw detection.

Design Parameters of Mango Wiggler	
Period Length $\lambda x/\lambda y$ [mm]	50.70/50.00
No. of Periods Nx/Ny	17.75/18
Peak Field B_{0x}/B_{0y} [T]	0.2-1.0







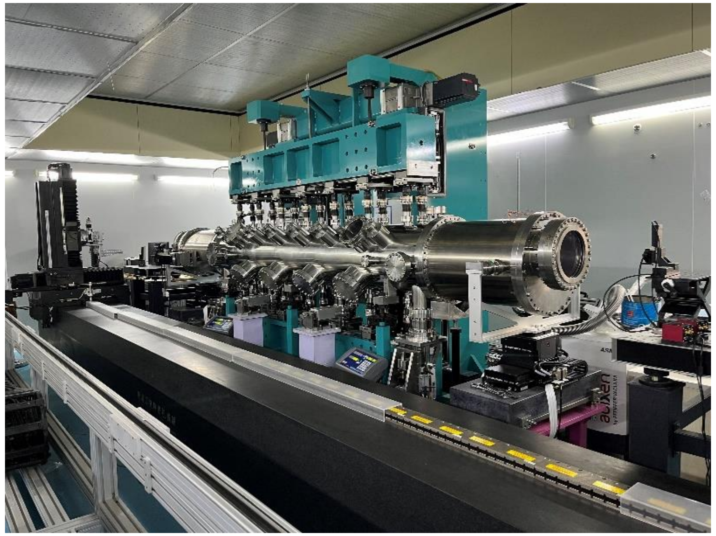


Insertion Device

In-vacuum IDs

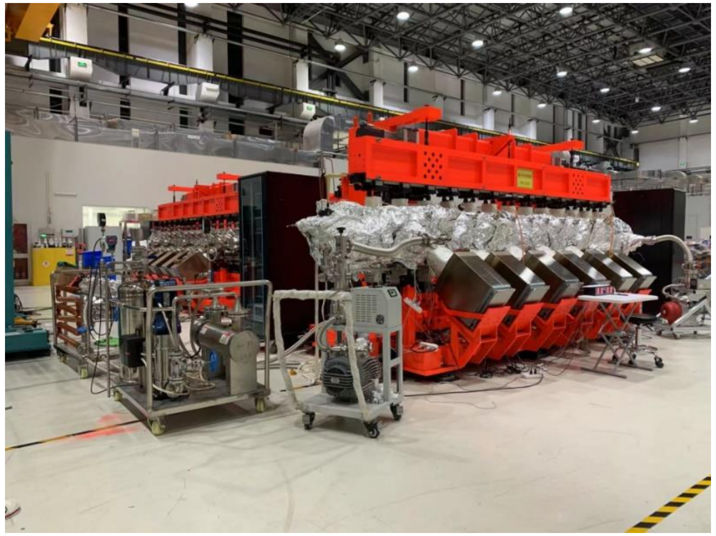
- The mass production of 11 in-vacuum IDs (6 CPMUs + 5 IVUs) completed
- The batch tuning is underway

Short period 12mm



CPMU in Tuning

IVU in Tuning

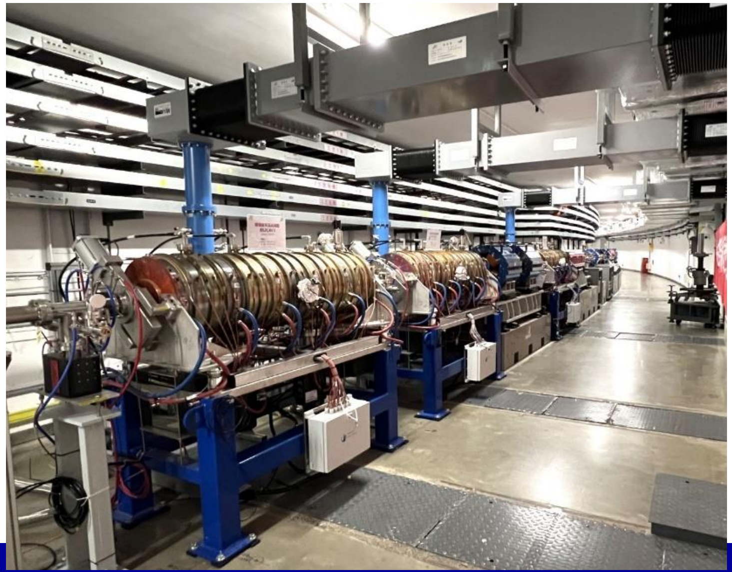


IVU in Baking

RF cavities

- 2022.12, all six 500MHz 5-cell copper cavities passed SAT at PAPS (c.w. 120kW)
- 2023.07, three 500MHz 5-cell **copper cavities installed in the Booster tunnel and commissioned**
- 2021.11, first 166MHz bare SRF cavity passed vertical acceptance tests
- 2022.06, first **166MHz jacketed SRF cavity passed vertical acceptance tests**
- 2023.06, first **166MHz cryomodule assembled** and moved into the horizontal test stand
- 2022.12, four **500MHz bare SRF cavities** produced and **passed vertical acceptance tests**

500MHz 5-cell copper cavities

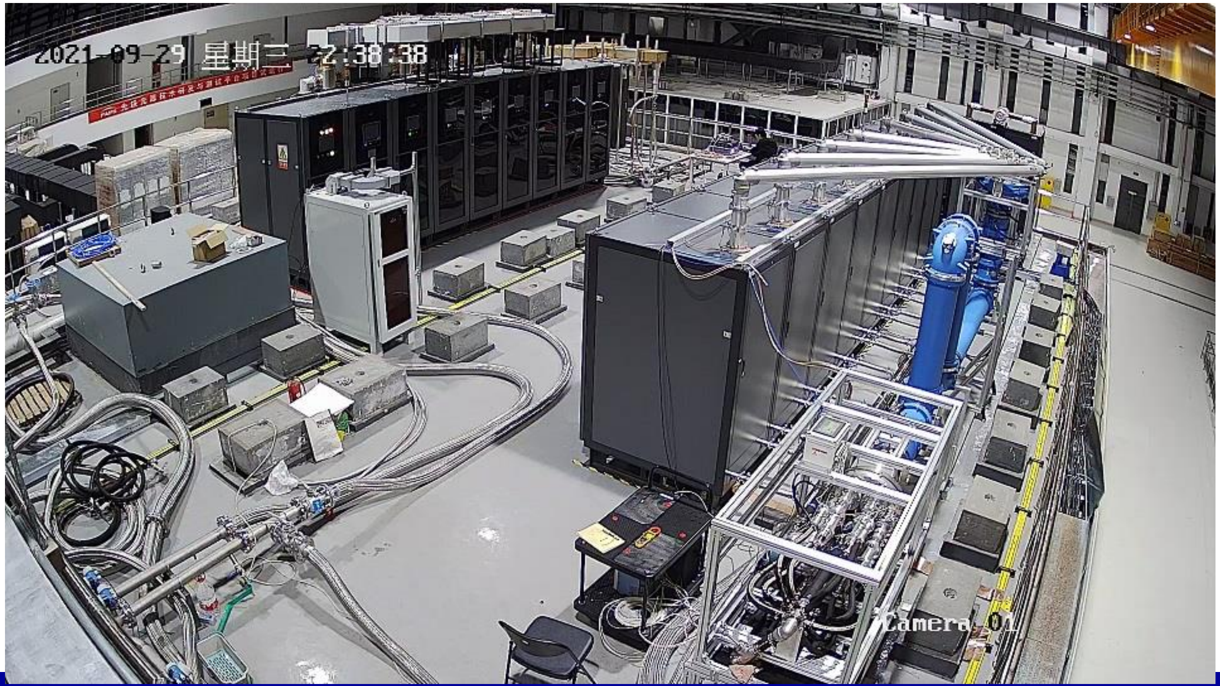


166MHz SRF cryomodule

500MHz SRF cavity string

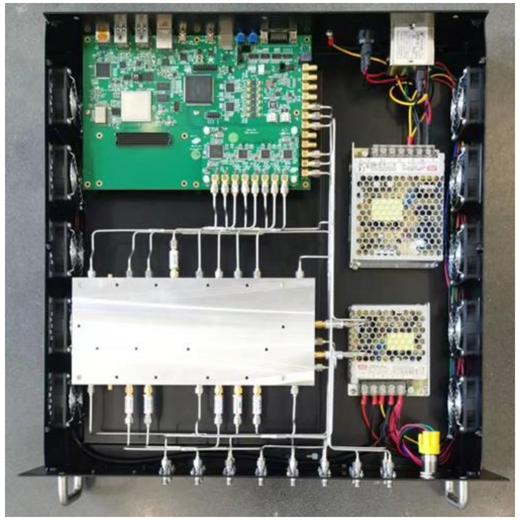
High-power RF system

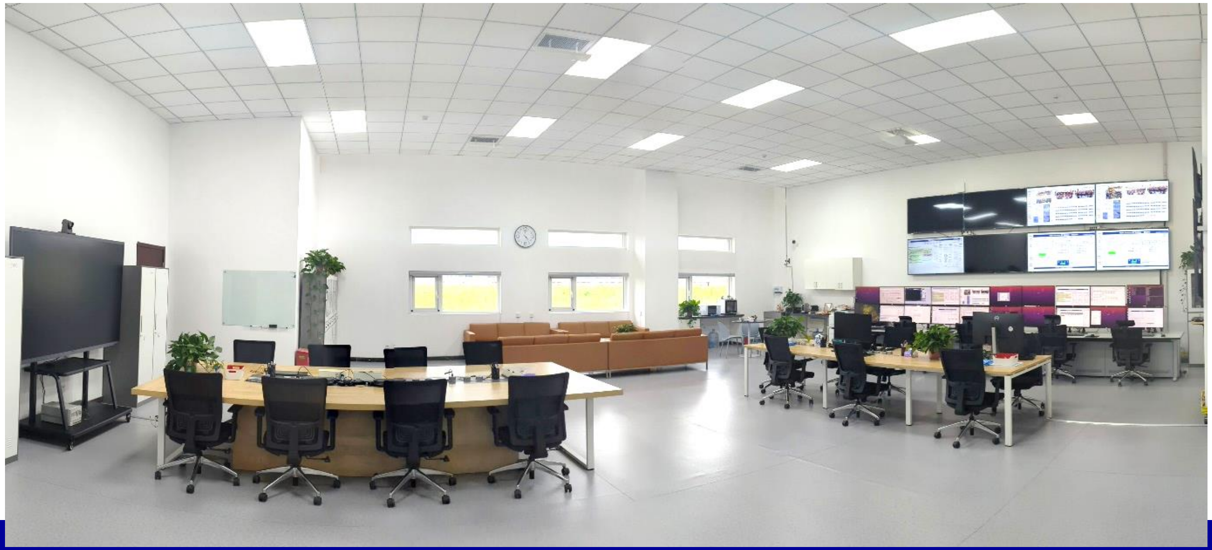
- 2021.10, 166MHz-260kW and 500MHz-150kW prototype SSAs passed essential tests at PAPS
- 2023.04, 166MHz-260kW and 500MHz-260kW **series SSAs production complete and passed FAT**
- 2023.07, **500MHz-100kW series SSAs complete and passed SAT** at Booster RF hall
- 2023.06, first 500MHz-150kW circulator installed at Booster and passed SAT

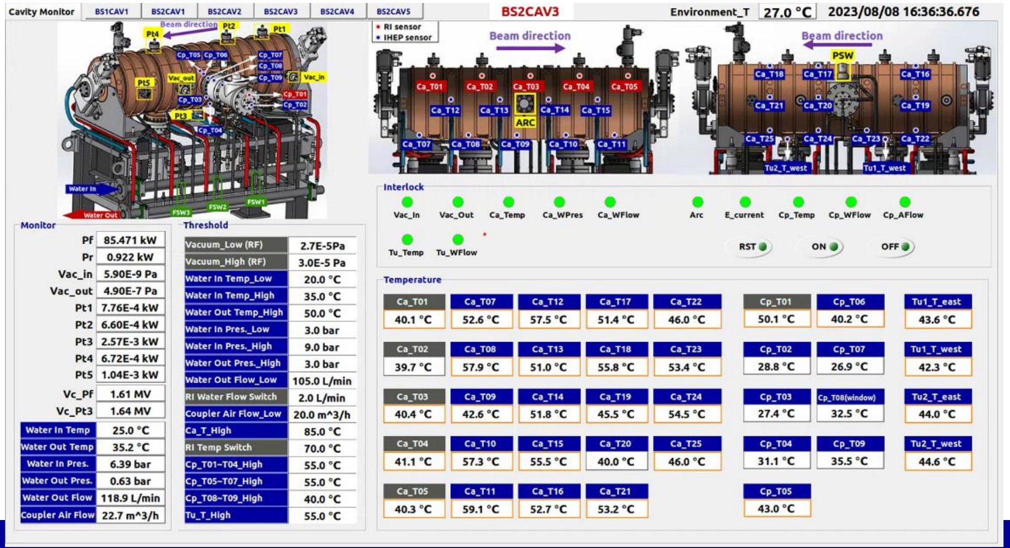


Low-level RF system

- 2022.12, XILINX-based LLRF in-house developed
- 2023.05, integration of cavity, SSA and LLRF at Booster complete
- 2023.07, **commissioning of booster RF complete**
- 2023.04, RF EPICS database start archiving data
- 2023.04, Booster RF control OPI developed







Cryogenics system

- Layout of the cryogenics system finished and met the technical requirements of HEPS micro-vibration requirement
- All cryogenic equipment of cryogenic hall, tank area and HEPS zone installed

Transport line from cryogenic hall to HEPS

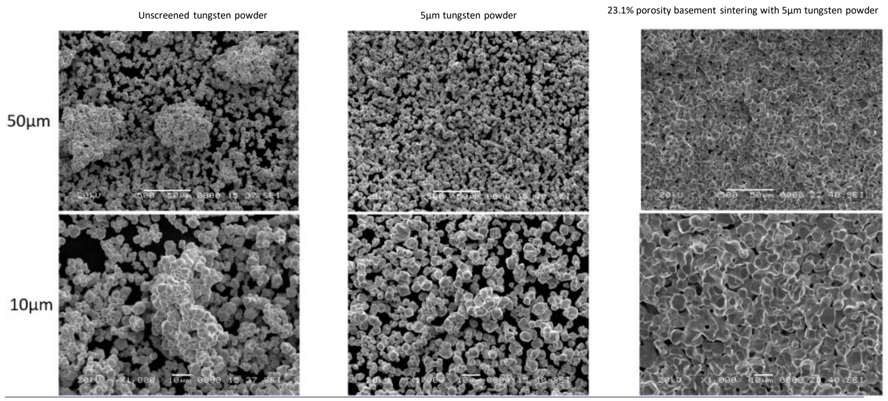
Tank area and cryogenic hall

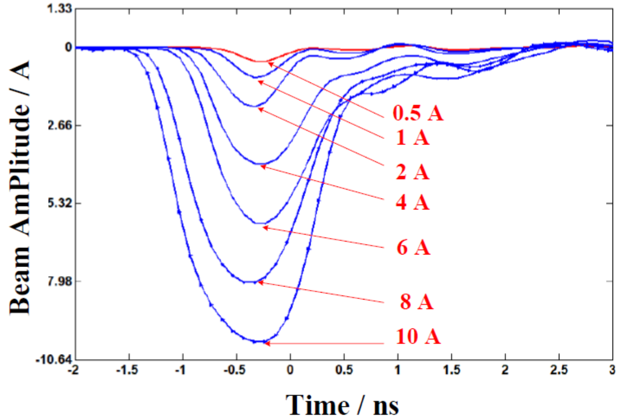
Linac microwave and power source

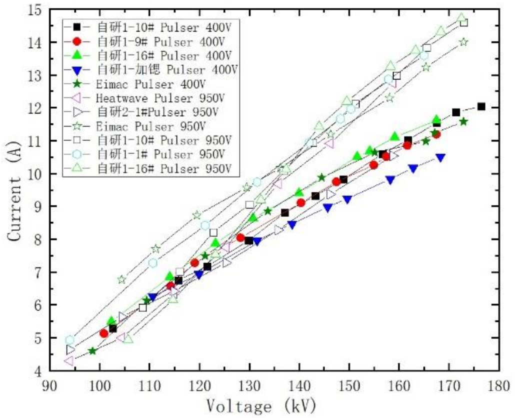
- **Cathode-grid Assembly R&D**

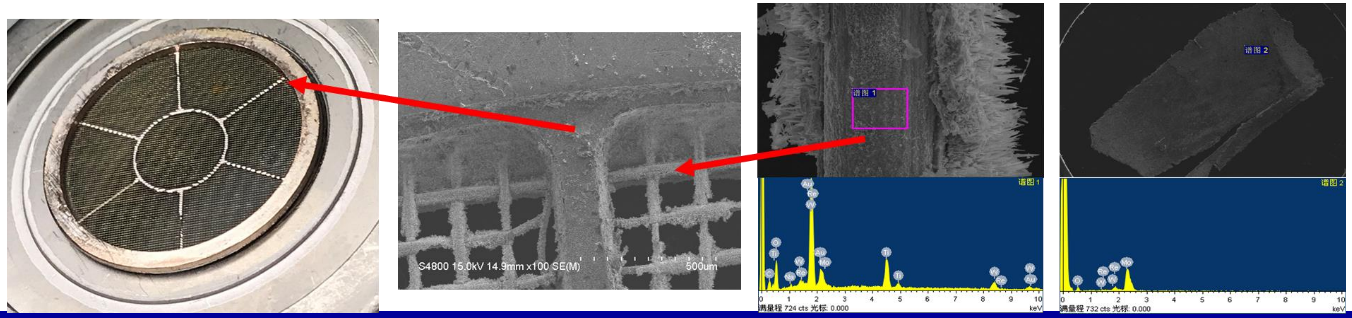
  - Assembly emission current satisfied E-gun of HEPS linac

  - Reliability and lifetime of assembly are under tests





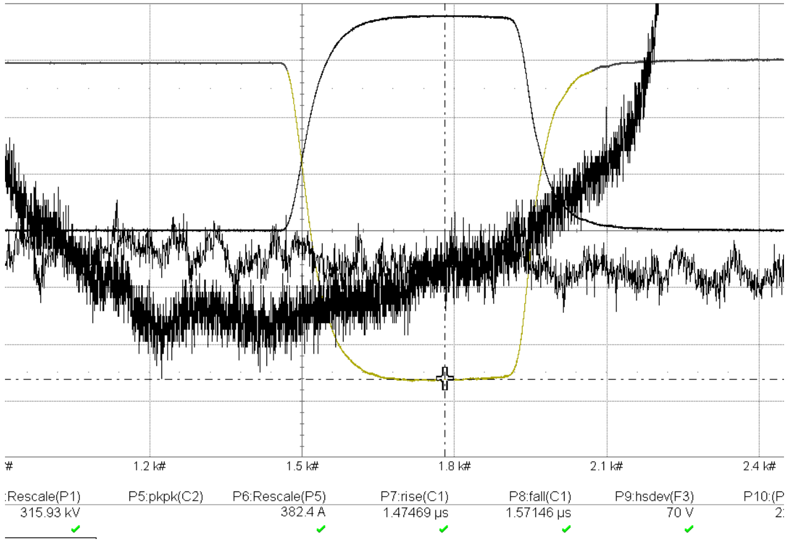




Linac microwave and power source

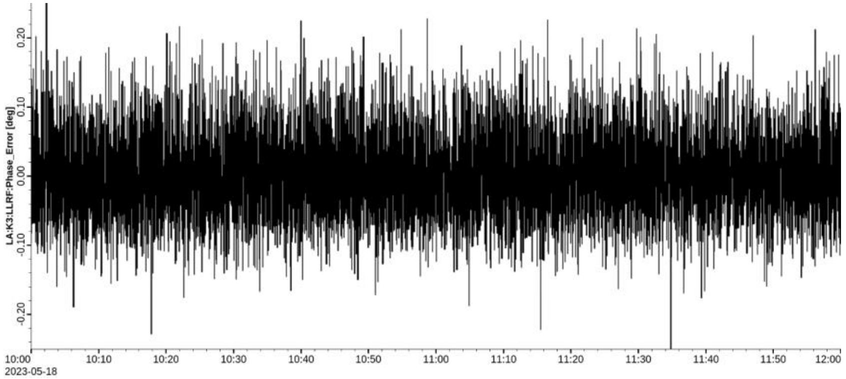
- **Solid-state modulator**
  - Completely eliminate instability and limited lifetime of thyratron
  - Solid-state modulator technology in-housed developed

Modulators in HEPS Linac Gallery



Pulse Repeat stability 0.018%
305kV/354.2A/30min

Microwave phase stability of Linac K3
2 hours p-p stability: 0.4°
2 hours RMS stability: 0.07°



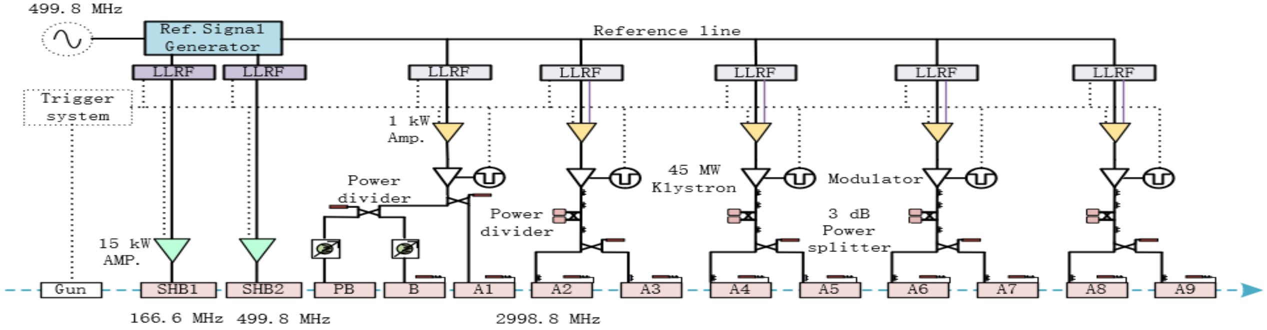
Linac RF system

- **Features**

- The accelerating structure adopts an round-shaped cavity, an elliptical cross-section iris design, and the coupler design is a single port doubly fed structure
- The pulse compressor design is a dual cavity structure with dual hole coupling, and internal water cooling
- The directivity of DC: 40dB, LLRF is fully digital

- **Milestone**

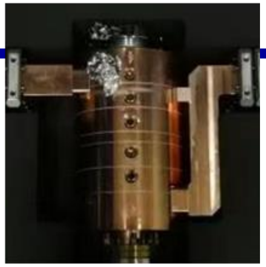
- 2019.6, microwave system design completed and begin to manufacture the component
- 2021.3, complete the acceptance of the first accelerating structure
- 2022.4, complete the installation of the accelerating structure and pass the final acceptance
- 2022.5, complete the installation and test of the microwave system and begin online high-power practice
- 2022.9, the energy reaches 500MeV at linac exit



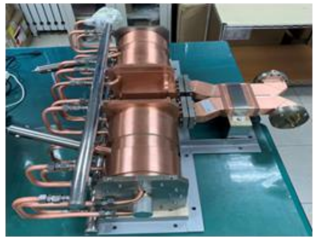
The layout of the linac RF system


SHB


Prebuncher (S-band)


Buncher (S-band)


S-band Accelerating structure


Pulse compressor


Directional coupler


3dB hybrid directional coupler


LLRF system

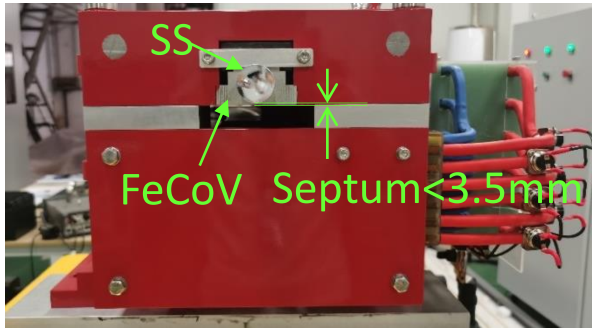

SiC load

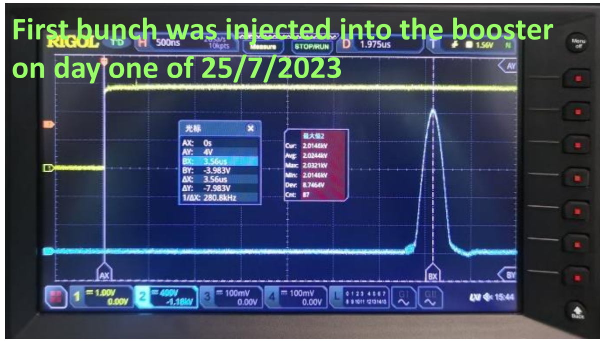

Phase shift & attenuation

Main components

Injection & extraction system

- **Booster**
  - All hardware including Lambertson magnets, kicker magnets and pulsers were delivered for installation in May 2023
  - The low-energy injection system has been put into operation for beam commissioning



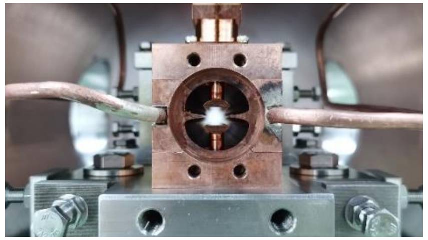


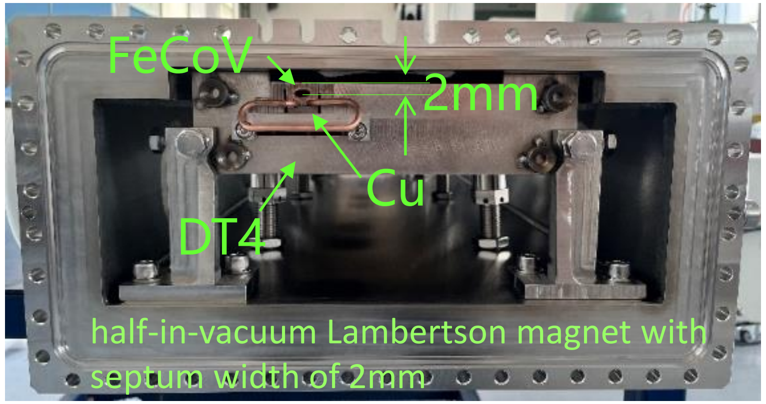
Injection & extraction system

- **Storage ring**

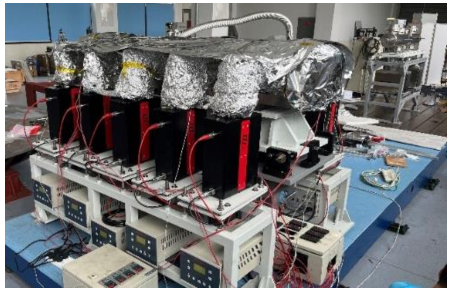
- Kicker: All strip-line kickers delivered on 24/7/2023
- Septum: the full-size prototype was completed in Jan. 2023 and 2 sets of final magnets are still under processing.

Fast kicker and pulser: pulse bottom width (3%-3%) < 10ns, pulse peak = ±15kV







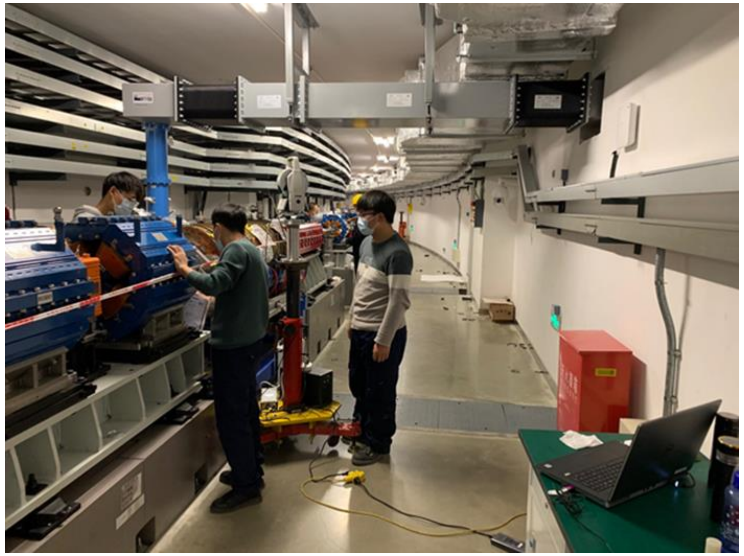



Alignment: Linac and Booster

- The initial alignment and smooth precise alignment of the 50-meter linear accelerator were completed from March to August 2022, with an alignment accuracy of **0.1mm**.
- From October to December 2022, the initial alignment of the 454-meter circumference booster was completed. From February to May 2023, two rounds of smooth precise alignment of the booster 's orbit were conducted with an alignment accuracy of **0.065mm**.
- All these alignment works have effectively improved the efficiency of beam commissioning and ensured stable beam operation. Currently, the linear tunnel is operating successfully, and the booster tunnel has completed beam commissioning. This demonstrates the correctness and practicality of the principle and procedure for achieving smooth precise alignment of the orbit.

Smooth precise alignment of linear accelerator

Smooth precise alignment of booster



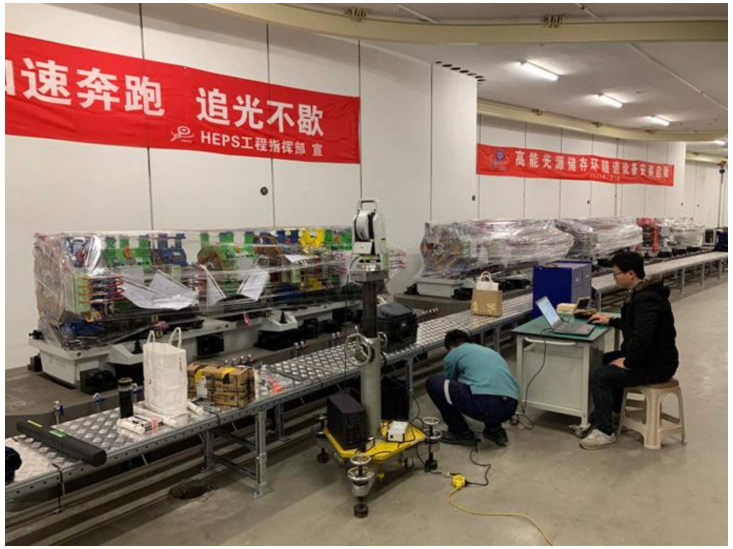
Initial alignment of booster

Alignment: storage ring

- For the first time in China, the laser multilateration measurement method is adopted to the pre-alignment of storage ring magnets of HEPS. **The spatial coordinate measurement precision of 6μm within a 6.5-meter control range have been achieved.** The system has reached a world-leading level in terms of stability and measurement efficiency. By August 2023, 217 out of 288 girders have been pre-aligned.
- The initial alignment of the storage ring is currently underway. It is being carried out using a conventional single tracker control network fitting positioning method. The deviations have been adjusted to 0.05mm, the instrument control network fitting positioning error is 0.4mm, and the magnet position error is 0.5mm, meeting the requirements for initial alignment. By August 2023, 156 out of 288 girders has been completed.

Pre-alignment of storage ring magnets

Pre-alignment of storage ring magnets



Initial alignment of the storage ring

Mock-up of storage-ring standard cell

- The operation space and interfaces have been checked, and pre-alignment scheme, transport scheme and other critical problems have been thoroughly tested

Aim to verify the feasibility of the magnet, vacuum chamber, BPM, etc. installation procedure

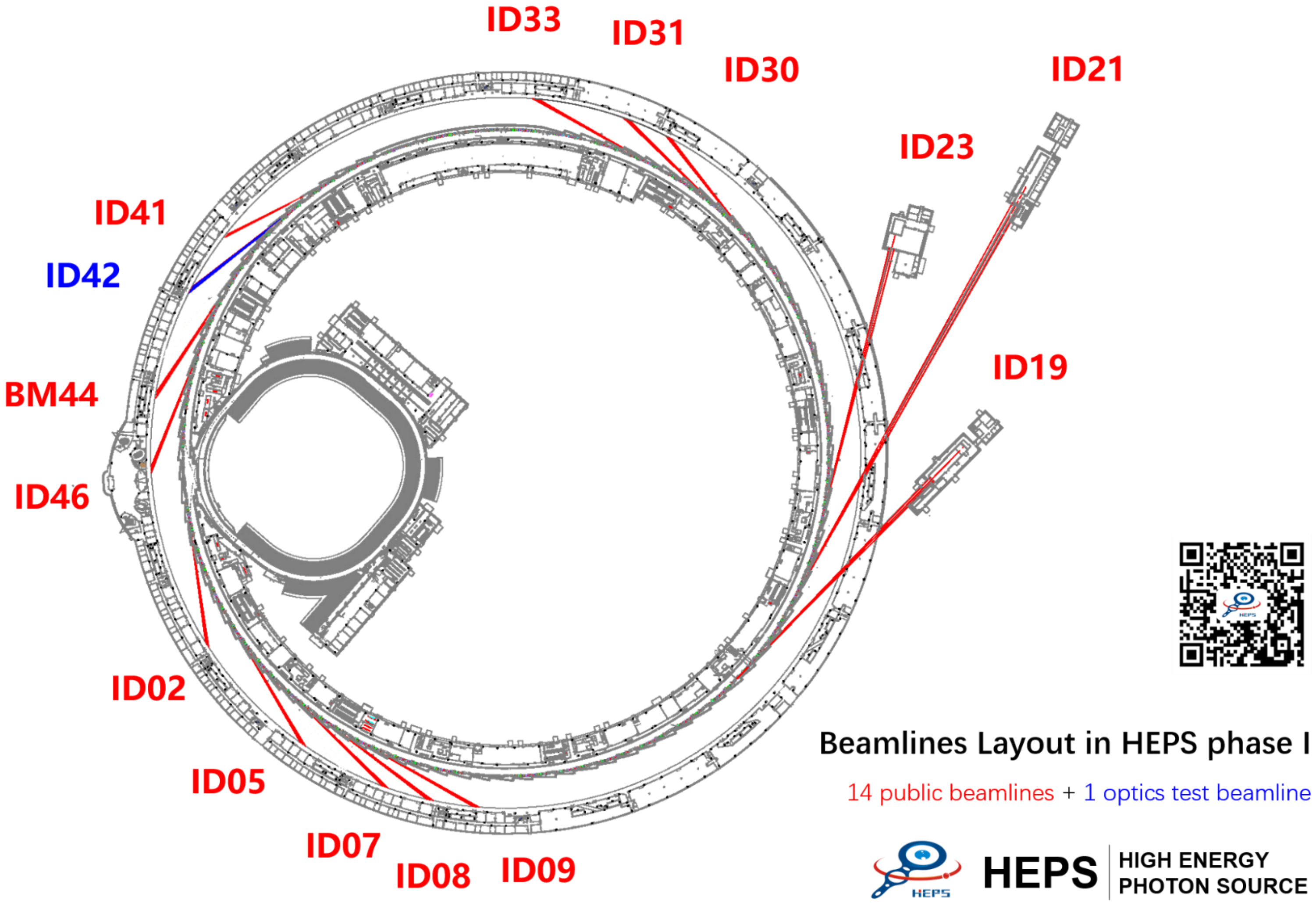
BEAMLINE

1. Beamlines design
2. R&D for beamline technologies

Beamlines design

Layout of 15 beamlines in Phase I

- 14 public beamlines: 13 IDs (3 long) + 1 BM
- 1 ID beamlines for optics test



Phase I Beamlines list

	Beamlines	Features
High Energy	Engineering Materials	50-170keV， XRD, SAXS, PDF
	Hard X-Ray Imaging	10-300keV, Phase and Diffraction contrast imaging, 200mm large spot, 350m long
High Brightness	NanoProbe	Small probe, <10nm; InSitu nanoprobe, <50nm; 180m long
	Structural Dynamics	15-60keV, single-shot diffraction and imaging; < 50nm projection imaging
	High Pressure	110nm focusing, diffraction and imaging
	Nano-ARPES	100-2000eV， 100nm focusing, 5meV@200eV, APPLE-KNOT undulator
High Coherence	Hard X-ray Coherent Scattering	CDI(<5nm resolution), sub-μs XPCS
	Low-Dimension Probe	surface and interface scattering, surface XPCS

Phase I Beamlines description

	Beamlines	Features
General beamlines	NRS&Raman	Nuclear Resonant Scattering and X-ray Raman spectroscopy
	XAFS	routine XAFS， plus 350nm spot and quick XAFS
	Tender spectroscopy	Bending magnet， 2-10keV spectroscopy
	μ-Macromolecule	1μm spot, standard and serial crystallography
	pink SAXS	pink beam, lest optics
	Transmission X-ray Microscope （TXM)	full field nano imaging and spectroscopy
Test beamlines	Optics Test	with undulator and wiggler source for optics measurement and R&D

Status of HEPS Beamline

- Designs
- Key technologies
- Procurement and Delivery
- Test and Installation
- Schedule

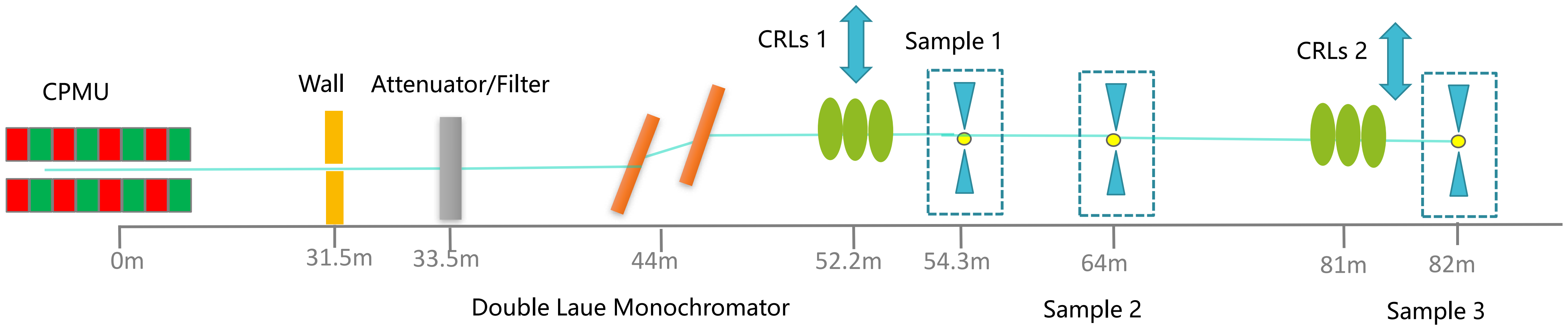
Engineering Materials Beamline

High energy X-ray for engineering materials

- Source, 2 x CPMUs for **photon flux >1×10^{12} @100keV**
- Mono, Laue monochromator, asymmetrically cut crystal, Double crystal, fixed exit

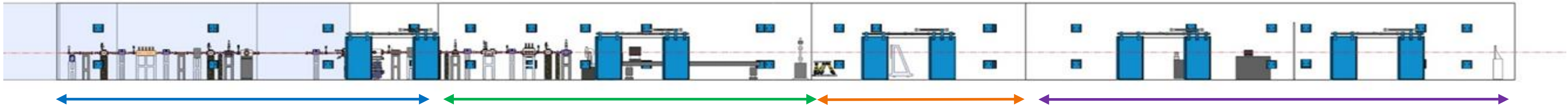
50keV~170keV , ΔE/E ~1×10^{-3} @100 keV

- Focusing, Home made Nickel-based Kinoform, **~2μm×2μm and submicron**

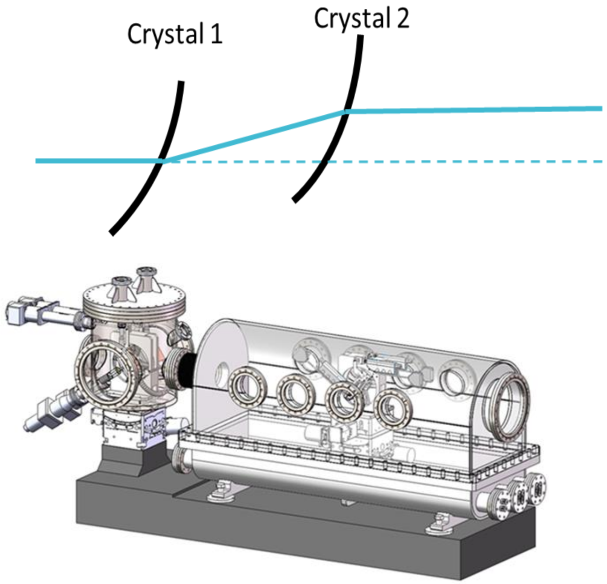


Engineering Materials Beamline

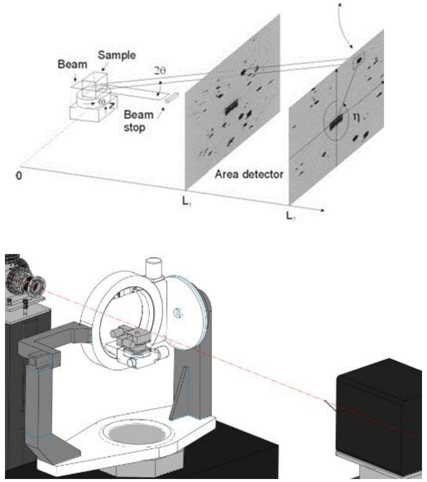
Layout of beamline and endstations



FOE: Laue optics

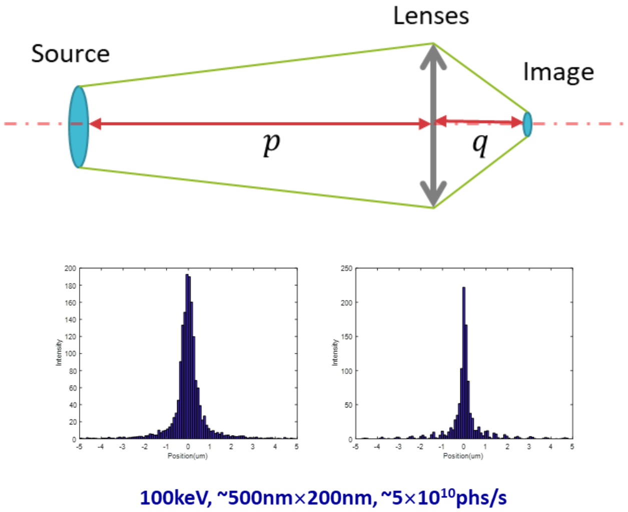


Hutch A: powder diffraction/3D XRD



Hutch B: large samples tensile mode heating mode

Hutch C: SAXS/micro XRD



Hard X-ray Imaging Beamline

High energy

GOALS: High sensitivity, Deep penetration, Multiscale mesoscopic spatial resolution, Large FOV, Multiple contrast mechanisms and compatible with diverse sample environments.

Probes： In-line phase contrast imaging; Diffraction Contrast Imaging

Application: Biomedicine: whole organ mesoscopic imaging

Engineering Materials

Fossils and Human Relics

Features: Large FOV and high Resolution

Ratio of spot size and PSF increase from 2k to 20k, 1000 times of voxels one CT

High sensitivity at high resolution & deep penetration case, very small PSF

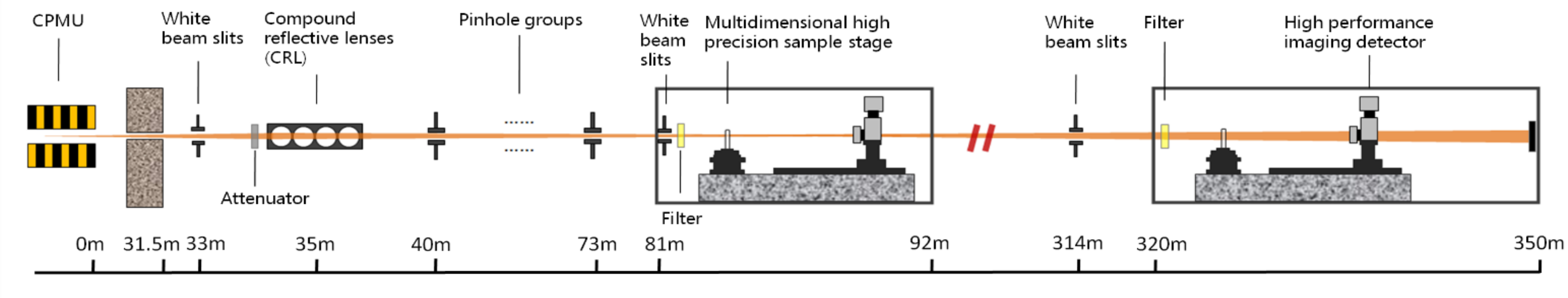
Hard X-ray Imaging Beamline

High energy

1xCPMU + 1xWiggler+1x Mango Wiggler； 350m long beamline

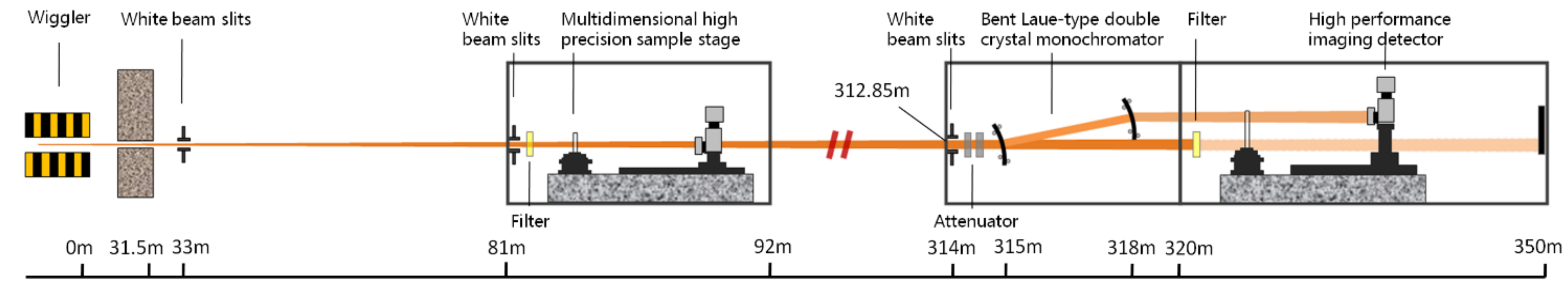
CPMU branch

10-90 keV



Wiggler branch

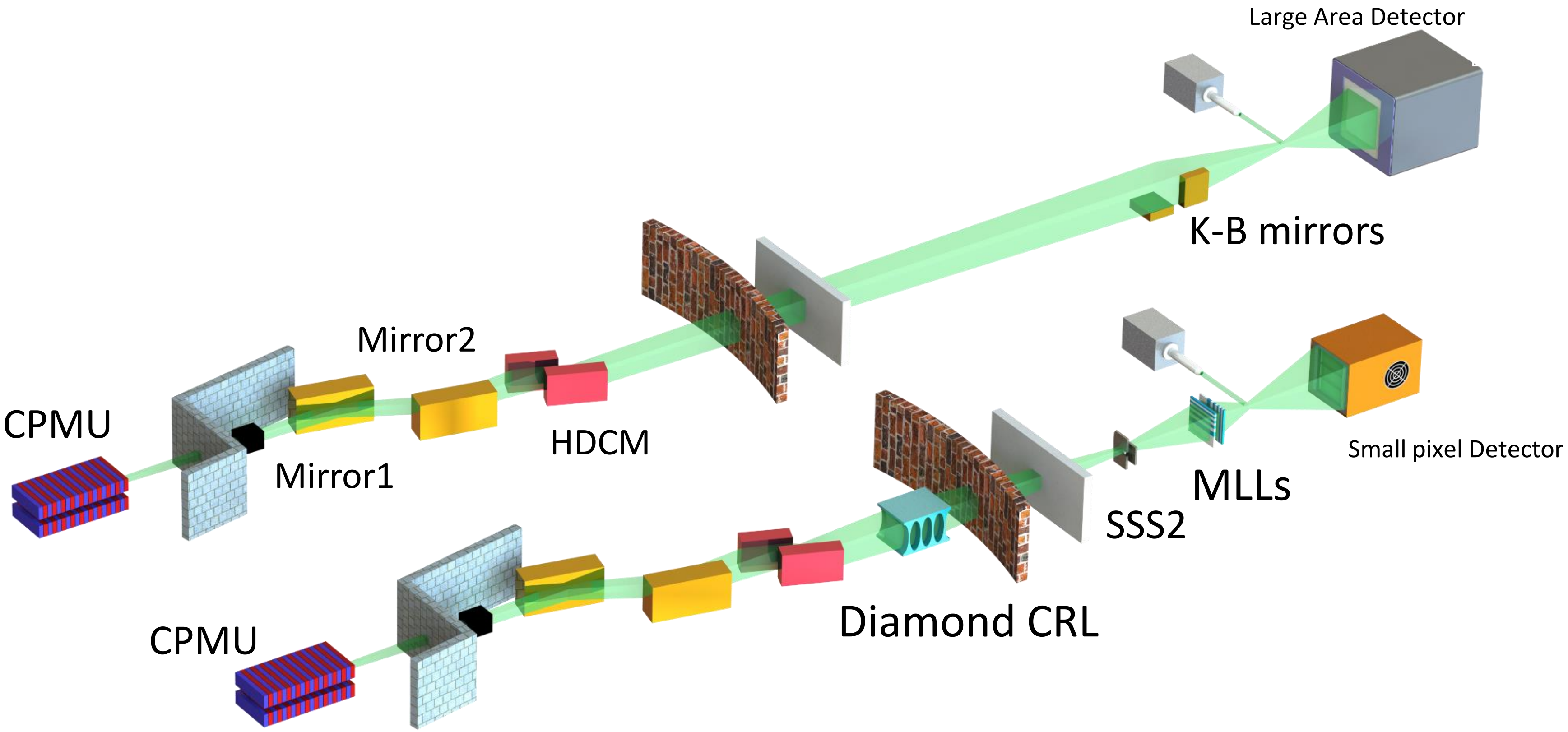
20keV—300keV



NanoProbe beamline

High brightness

Pursuing nanofocusing in two working mode



Optical Layout of Nanoprobe beamline

In-situ mode (K-B mirror)

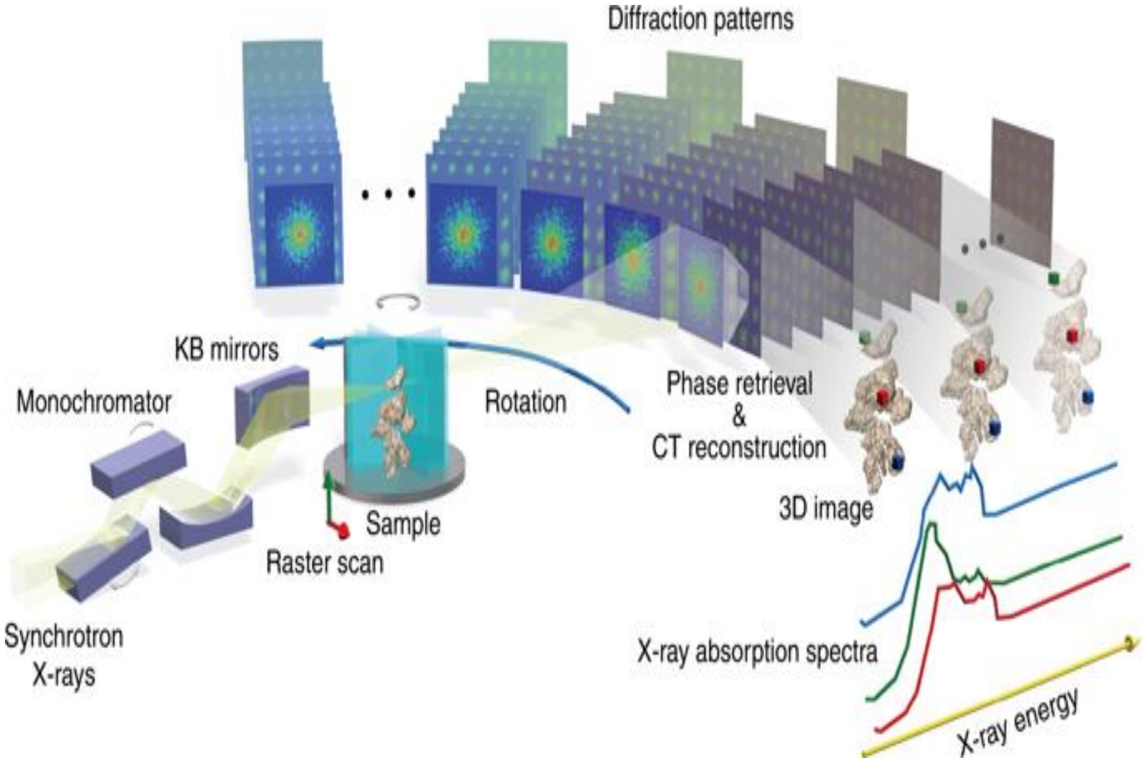
Probe Size: ＜50nm
Work Distance: 50mm
Flux: 10^{11}-10^{12} phs/s

High resolution mode (Mutlilayer Laue Lens)

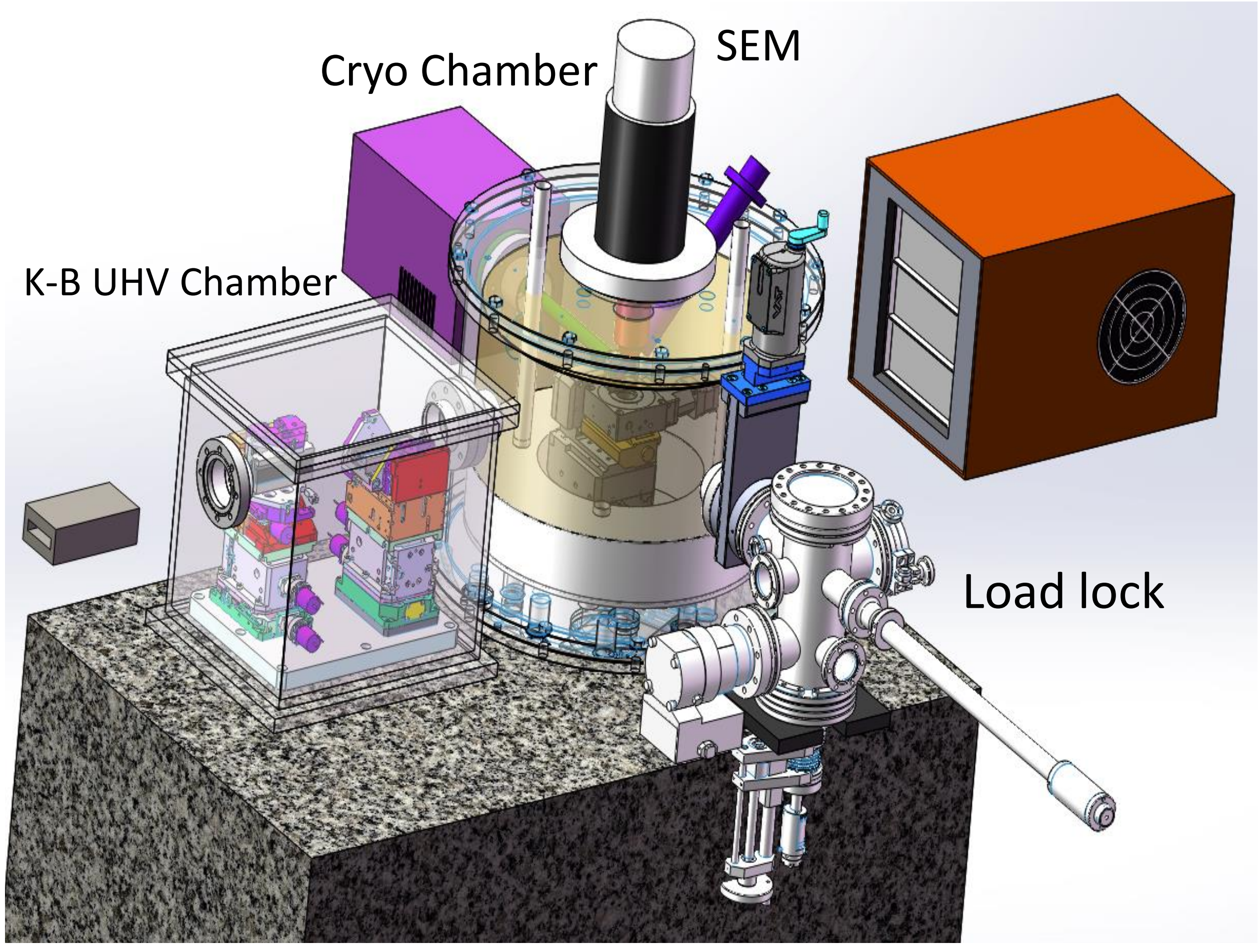
Probe Size: ＜10nm
Work Distance: 2mm
Flux: $10^{10\sim11}$ phs/s

Multimodal Probing

nano-XRF, nano-XRD, nano-XANES
Ptychography, Spectra-Ptychography



M. Hirose, Nature communication,2019

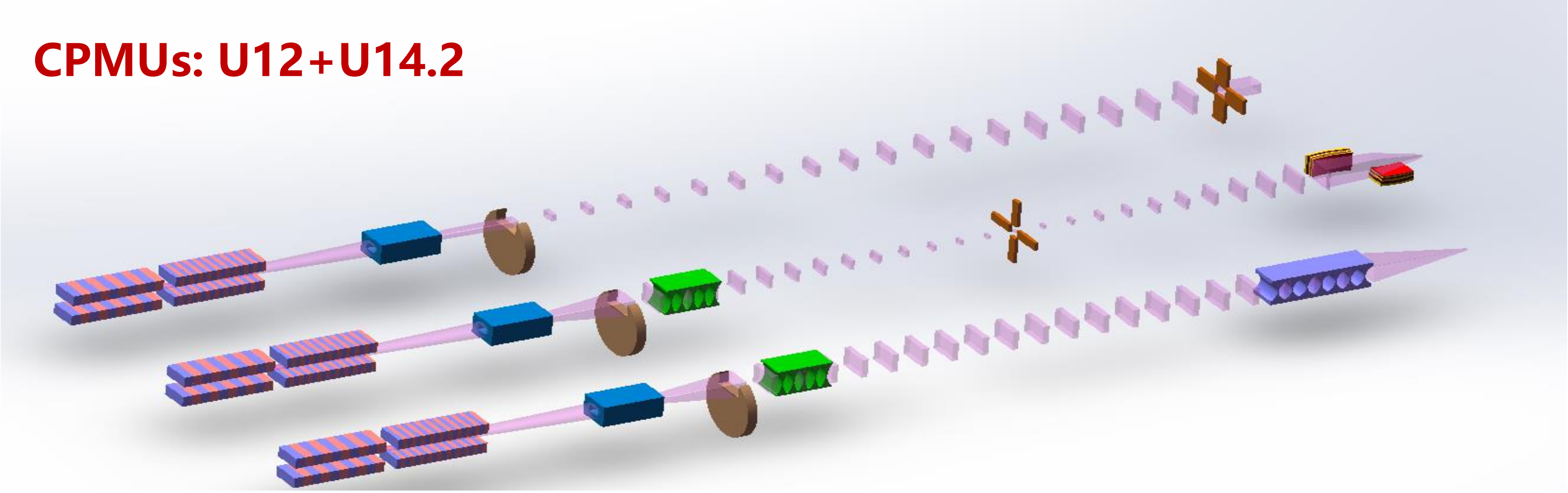


Structural Dynamic Beamline

Single shot probes for Irreversible progress

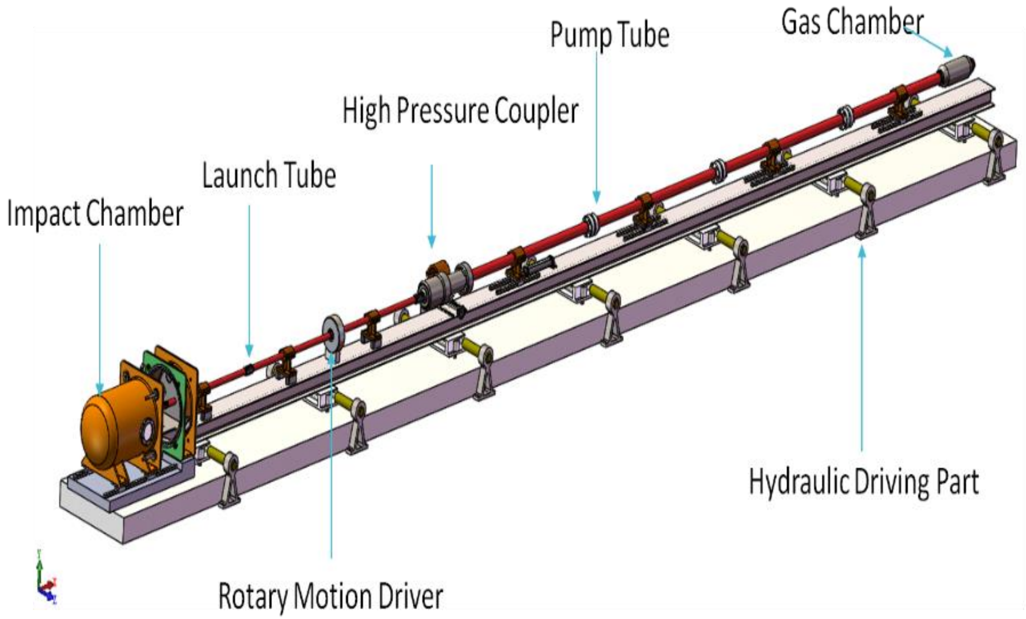
Energy range	23,44,65 keV
Energy resolution	0.3-10%
Flux per pulse	$>10^9$ phs/pulse
Temporal resolution	~400 ps

CPMUs: U12+U14.2

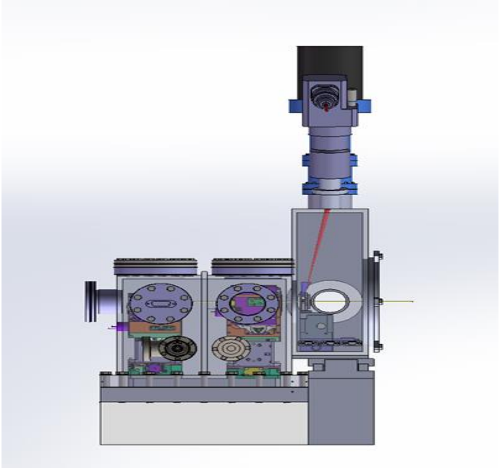


Dynamic experimental instrumentation

Dynamic loading:
Gas gun, Hopkinson bar, High power laser,
Additive Manufacturing
Probes: XRD,SAXS,XPCI,
Magnified nano-imaging



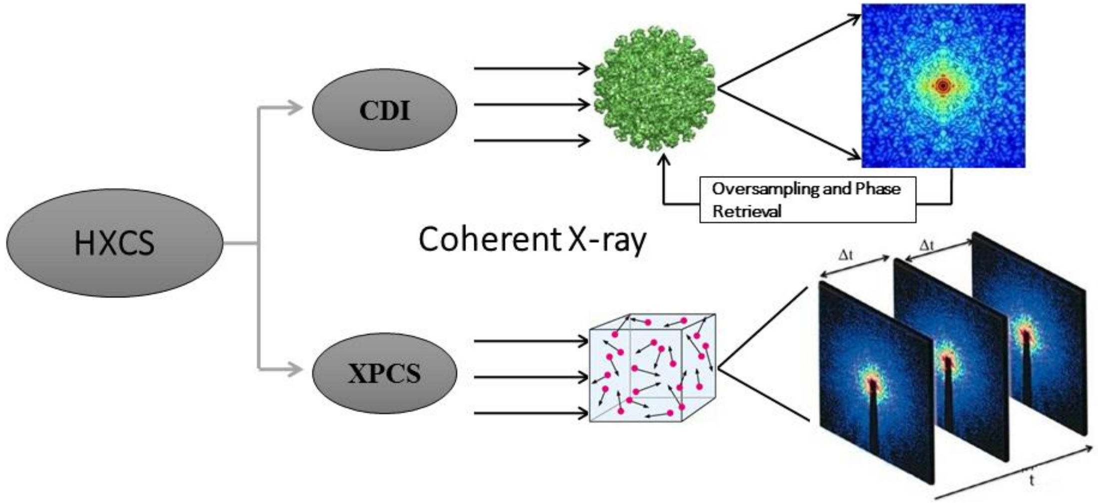
Additive Manufacturing



Hard X-ray Coherent Scattering beamline

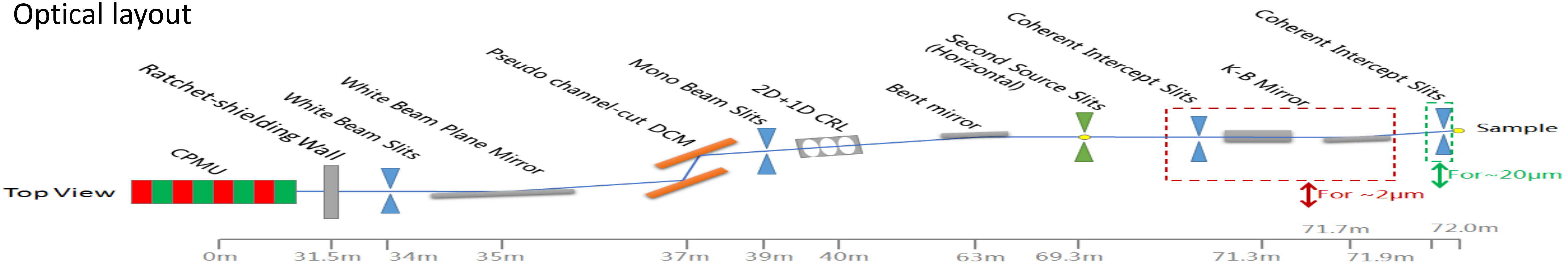
High coherence

Dedicated to Coherent Diffractive Imaging (CDI) and X-ray Photons Correlation Spectroscopy (XPCS)



	Specifications
Energy range	7-25keV
Energy resolution	10^{-4} Si(111)
Coherent flux	$>10^{12}$ph/s @12.4keV
Beam size	2μm (WAXS CDI&XPCS) 20μm (SAXS CDI&XPCS)
Endstastion	CDI (resolution<5nm) XPCS (resolution<1μs)

Optical layout



Key technologies

- X-ray optics design
- Thermal management
- Optics metrology
- Monochromators
- Mirror systems
- Wavefront preservation and crystal/device fabrication
- Nano-positioning instrumentation
- Time-resolved instrumentations
- X-ray detector
- Data acquisition and analysis

Supported by both HEPS and Platform for Advanced Photon Source Technology R&D (PAPS)

See M.Li's yesterday talk

Procurement and Delivery

> 2/3 contracts signed

- Front ends for 15 beamlines delivered by October 2023.
- Enclosures, utilities and safety interlock system delivered 50%
- Optics

  75% mirrors delivered by July 2023.

  First batch of the diamond CRL delivered.
- Opto-mechanics

  All mirror vessel systems for group #1 beamline (Beamlines from BM and in-air insertion devices) delivered.

  4 monochromators delivered.
- Detectors： Advanced pixel array detectors package ordered

Test and installation- Front ends

14 of 17 front-ends delivered

Factory acceptance

Installation start

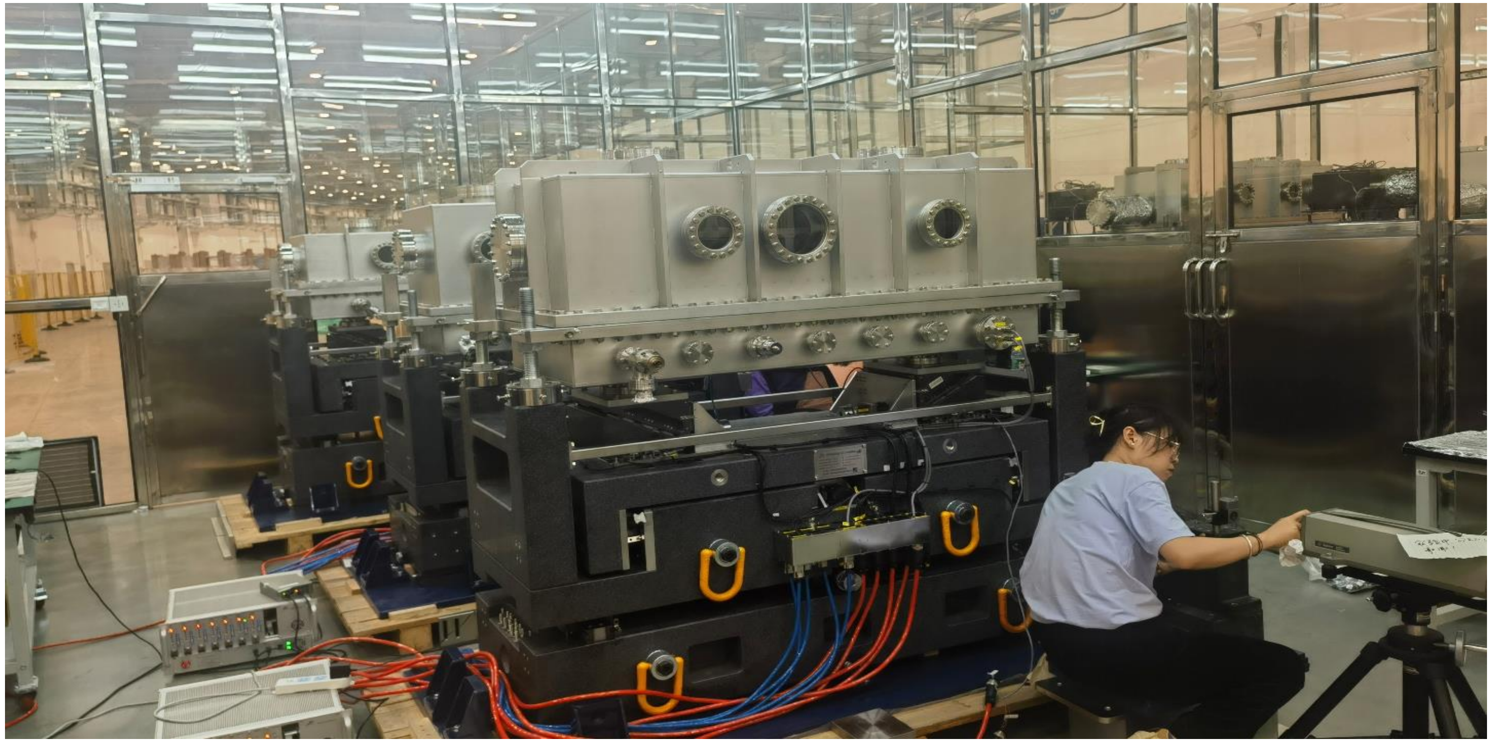
Test and installation - X-ray Mirror systems

Focusing, collimating mirrors

38/40 are designed by HEPS teams

Factory acceptance

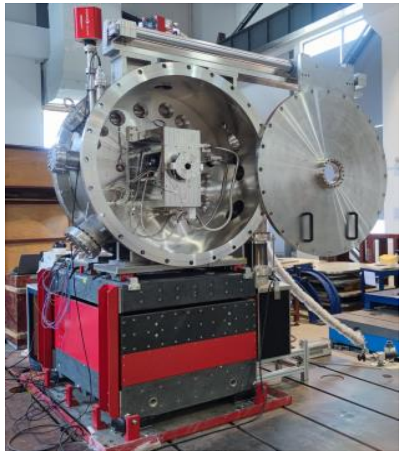
Test measurement after delivery



Test and installation-Monochromators

VDCM

HDCM



Fast-scan DCM

HR-DCM

First Double Crystal Monochromator installed at 2023/7

Test and installation- Enclosures

Schedule

- Group 1 beamline,

Test finish in the first half of 2024

Commissioning in the second half of 2024

- Group 2 beamline

Test finish in the first half of 2025

Commissioning in the first half of 2025

Future Plans: HEPS follow-up beamlines

- Criteria for HEPS beamline selection: **Scientific and Industrial questions as well as cutting-edge experimental methods motivated in 4GSR.**
- Upon schedule of insertion installation, without impeding the operation of existing BLs, 4-5 ID installed per year
- 32 bls has been planned

Fields	Material	Physics	Chemistry	Envir.	Energy	Industry	Bio.	Meth.
BL	3 ID, 3 BM	5 ID, 1BM	1 ID, 5 BM	2 ID	2 ID, 1 BM	1 ID, 4 BM	2 BM	2 ID

- Organizing institutionalization research teams/projects based on HEPS
- Materials
- Chemistry (Dynamic properties of catalysis)

Summary

- HEPS is a 4th generation, high energy, ultra-low emmitance SR facility. It is the key facility of Huairou Science City.
- A series of projects, HESP-TF, PAPS, Auxiliary building, are also carried on.
- The HEPS project progress in time. Civil construction was finished in Aug. 2022. LINAC is ready. Booster is in commissioning. Storage ring, beamlines and end-stations are in installation.
- No show stoppers to start storage-ring commissioning next year.


THANKS FOR YOUR ATTENTION!
photo in July 2023