中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

IHEP SRF accelerator and infrastructure introduction

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The Sixth Asian School on Superconductivity & Cryogenics for Accelerators (ASSCA 2025)

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Content

introduction

From the first ASSCA in 2019 to the sixth ASSCA in 2025, the superconducting and cryogenics technology have been made great progress, the quantity of superconducting accelerator and research infrastructure under operation or under construction also from zero to around 20 , China's superconducting accelerator is in its golden age of history.

Typical superconducting and cryogenics facilities in China

Name	Lab	T (K)	Capacity	Status	
BEPC-II	IHEP	4.5	1kW @ 4.5. K	Operating	
ADS Injector I	IHEP	2	100W@2K	Operating	
PAPS	IHEP	4.5/2	300W@2K	Operating	
HEPS	IHEP	4.5	2kW @ 4.5. K	under construction	
CEPC	**IHEP**	**2/4.5**	**4*18KW@4.5K**	planning	
CSNS II	IHEP	2	1KW@2K	**Under construction**	
ADS Injector II	IMP	4.5	1000W@4.5K	Operating	
HIAF	IMP	2	2KW@2K 10KW@4.5K	under construction	
CIADS	IMP	2	4.8KW@2K 18KW@4.5K	under construction	
SSRF	SARI	4.5	600W@4.5K	Operating	
SSRF II	SARI	4.5/2	60W@2K	Operating	
SHINE	**SARI**	**2**	**13KW@2K**	**under construction**	
DALS	**DICP**	**2**	**370W@2K**	**under construction**	
S^3FEL	**IASF**	**2**	**10KW@2K**	**under construction**	
HALF	**USTC**	**4.5**	**500W@4.5K**	**under construction**	

SRF Accelerator Projects at IHEP

	Operation	Construction	Design & R&D
Collider	**BEPCII** (1.89 GeV, 2 CAV, since 2006)	**BEPCII upgrade** (2.35 GeV, 4 CAV, complete in 2024)	**CEPC** (45.5-180 GeV, 288 ~ 980 CAV)
Synchrotron Light Source	**BSRF** (2.5 GeV, 2 CAV, since 2006)	**HEPS** (6 GeV, 10 CAV, complete in 2025)	
Proton & Heavy Ion	**ADS injector I** (10 MeV, 14 CAV, since 2016)	**CSNS-II** (300 MeV, 54 CAV, complete in 2028)	**CSNS-III** (1 GeV)

Superconducting RF Systems at IHEP

Light Sources & FELs

BSRF, HEPS, CW FEL, ERL

166 MHz (HEPS)
World's first very low freq
β=1 module

1.3 GHz (FEL, CEPC, ILC)
World's first mid-T high Q module

HEP Colliders

BEPCII&U, CEPC, ILC

500 MHz (BEPC-II&U, HEPS)
In-house-made, long-term operation
in large scientific facility

650 MHz (CEPC, ADS, CSNS)
World's first 650 MHz cryomodule

High Intensity Proton Linacs

ADS, CSNS-II, *v* factory

325 MHz (ADS)
World's first spoke cavity linac

324 MHz (CSNS-II)
China's first double-spoke module

Content

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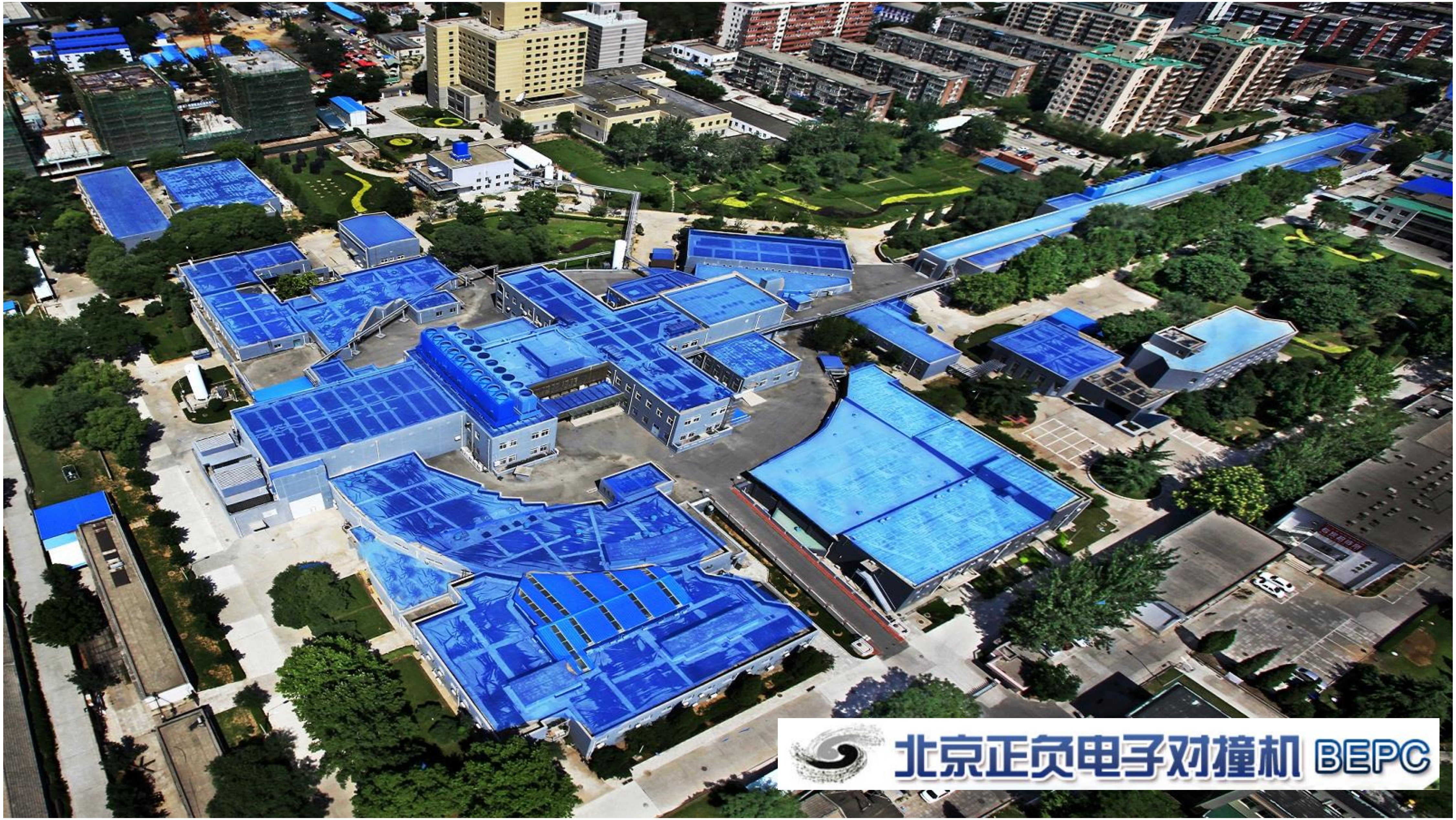
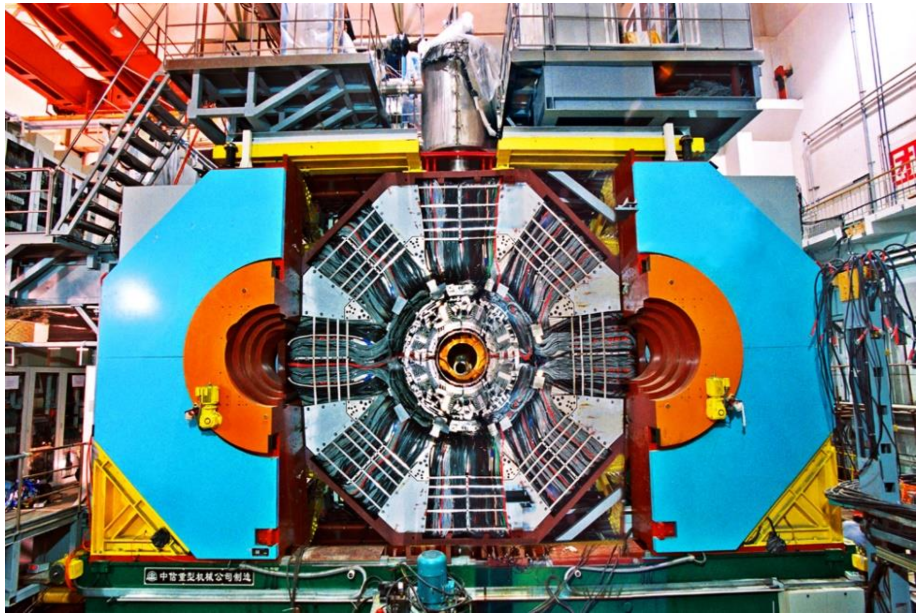
IHEP BEPCII and Upgrade



BEPCII

- Beijing Electron Positron Collider Ⅱ (BEPCII) and Beijing Spectrometer (BES Ⅲ)， first superconducting accelerator in China, and also the first time superconducting magnets were used at the collide point.
- BEPC Ⅱ have past the government acceptance test in 2008



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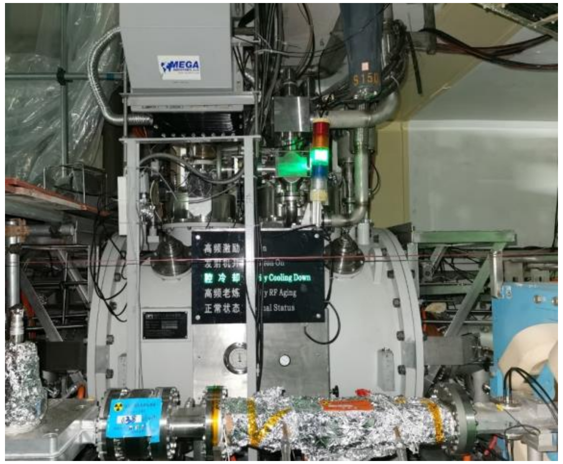
BEPCII SRF System

- BEPCII SRF system stable operation since 2006 with two imported cavities from Japan and in collaboration with KEK, reached design luminosity of 1x10^{33} cm^{-2}s^{-1} （910 mA @ 1.89 GeV） in 2016.
- In 2017, east cavity replaced with in-house-made cavity and module, stable operation till now.
- Three imported sub-systems (SRF cavity and module, LLRF, RF power source) have been replaced with in-house-made ones.



In-house-made 500 MHz cavity and module

made in 2011, stable operation since 2017

Digital LLRF system

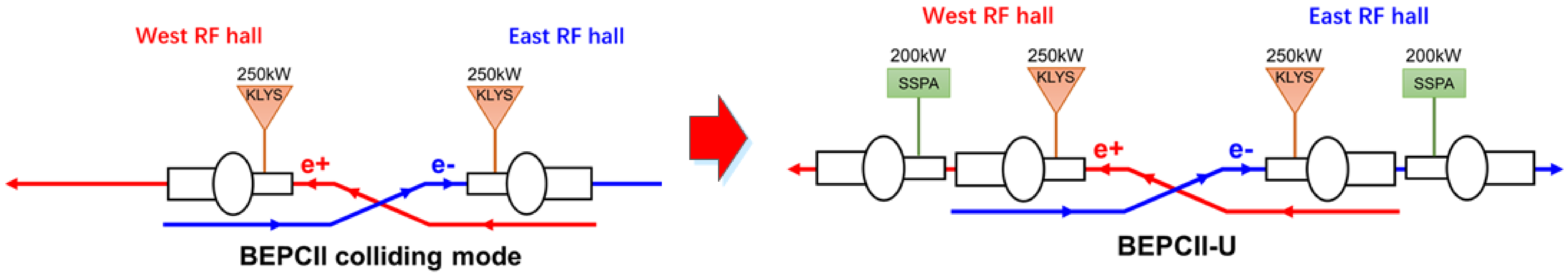
Stable operation since 2019

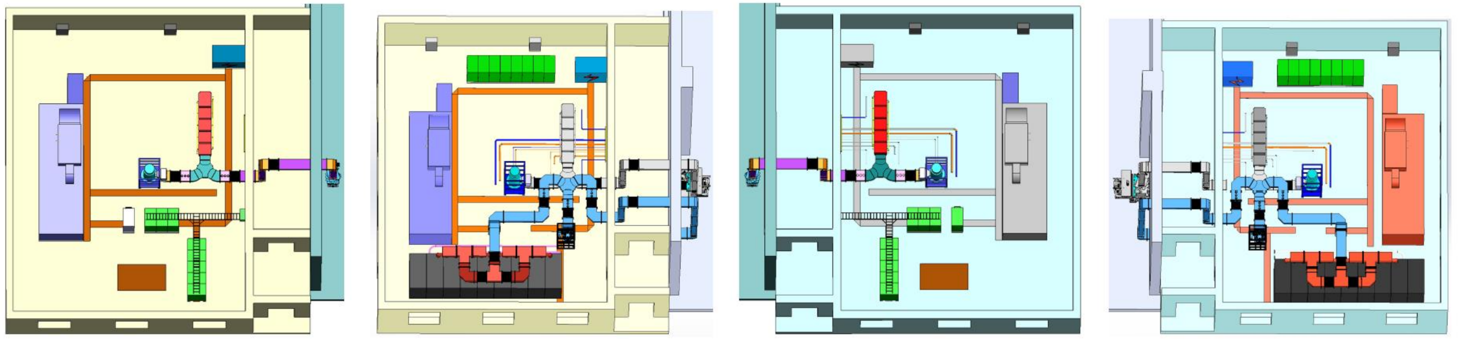
200 kW SSA

Operation since Oct. 2023

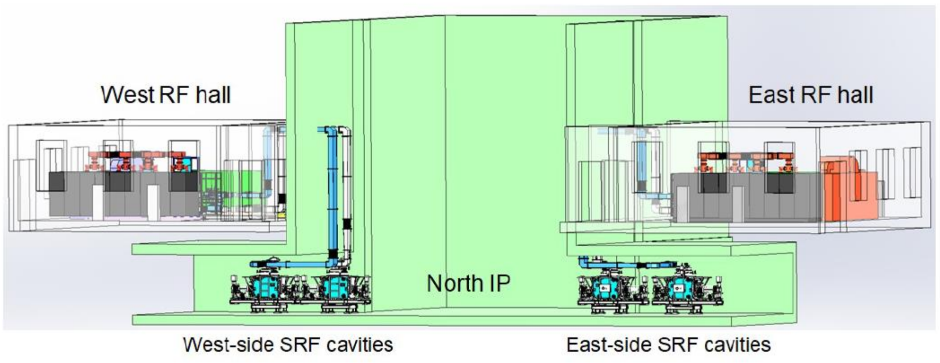
BEPCII-Upgrade SRF System

- BEPCII-U：Add two cavities and SSAs in 2024.
- Further R&D in 500 MHz cavity, LLRF and SSA.





(a) West RF hall (BEPCII) (b) West RF hall (BEPCII-U) (c) East RF hall (BEPCII) (d) East RF hall (BEPCII-U)



BEPCII-Upgrade SRF System

Table 1: Main parameters of BEPCII and BEPCII-U.

Parameter	Symbol	BEPCII	BEPCII-U	Unit
Circumference	C	237.53	237.53	m
Beam energy	E_0	1.89	2.35	GeV
Beam current	I_0	910	900	mA
Bunch number	N_b	120	120	-
Total energy loss per turn	U_{tot}	0.116	0.277	MeV
Total power loss to SR	P_{SR}	106	250	kW
Parasitic loss	P_{HOM}	7.7	30	kW
Total beam power	P_b	114	290	kW
Revolution frequency	f_{rev}	1262.1	1262.1	kHz
Synchrotron tune	ν_s	0.03	0.04	-
Bunch length	σ_z	14	12	mm
Momentum compaction factor	α_p	0.018	0.017	-
RF frequency	f_{rf}	499.8	499.8	MHz
Total RF voltage	V_{rf}	1.6	3.3	MV
Radiation damping time (x)	τ_x	24.2	12.6	ms
Radiation damping time (y)	τ_y	25.8	13.4	ms
Radiation damping time (z)	τ_z	13.4	6.9	ms
β function at straight section	β_x	15	20	m
β function at straight section	β_y	15	20	m

Table 3: RF parameters for BEPCII-U (breakdown).

Parameter	Existing	To be added	Unit
RF frequency	499.8	499.8	MHz
Number of cavities	2(+1)	1	-
RF voltage per cavity (V_c^{op})	1.65	1.75	MV
Cavity unloaded Q at V_c^{op}	$\geq$5e8	$\geq$1e9	-
Operating temperature	4.2	4.2	K
Nominal RF power per cavity	145	145	kW
Loaded Q	2e5	2e5	-
Cavity loaded bandwidth	2.5	2.5	kHz
Number of RF stations	2	2	-
Number of transmitters	2	2	-
Transmitter type	Klystron	SSA	-
Nominal power per transmitter	250	200	kW
Min. output power per transmitter (including 15% transmission loss)	165	165	kW
FPC designed power (CW)	200	200	kW
Number of LLRF	2	4	-
Specified amplitude noise (pk-pk)	$\pm$1	$\pm$0.5	%
Specified phase noise (pk-pk)	$\pm$1	$\pm$0.5	$^\circ$

BEPCII-U 500 MHz Cavity and Cryomodule

- One 500 MHz cavities for BEPCII-U and two 500 MHz third hormonic cavities for HEPS.
- Prevent cavity buckling by thicker Nb sheet (2.5 mm to 3.7 mm), deep drawing instead of spinning, adding stiffening rings.

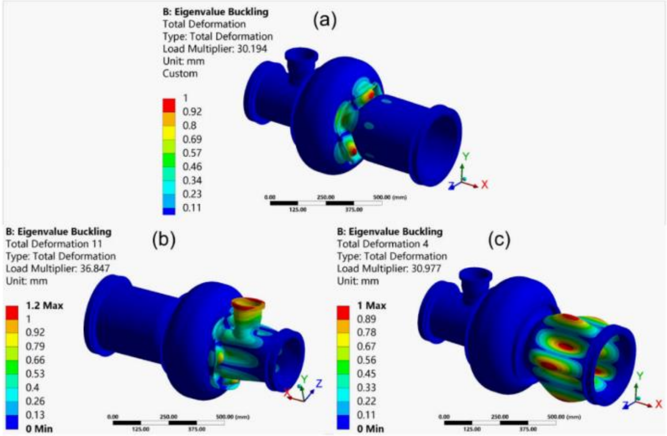
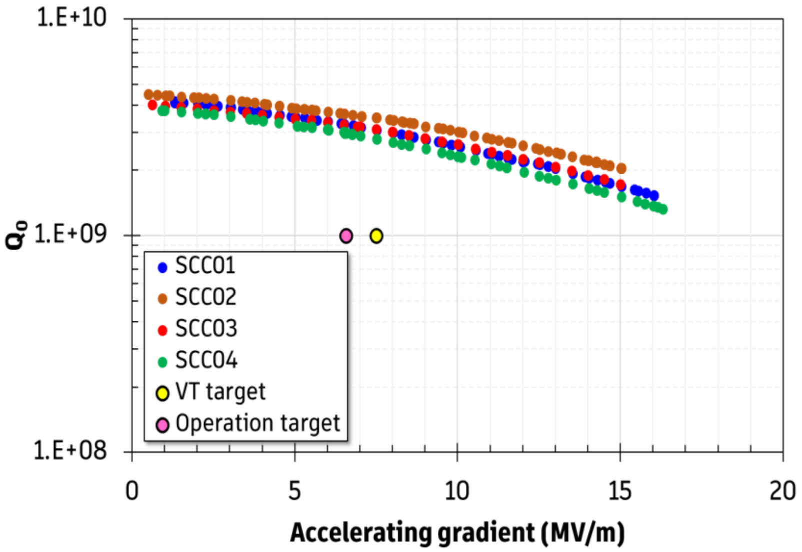
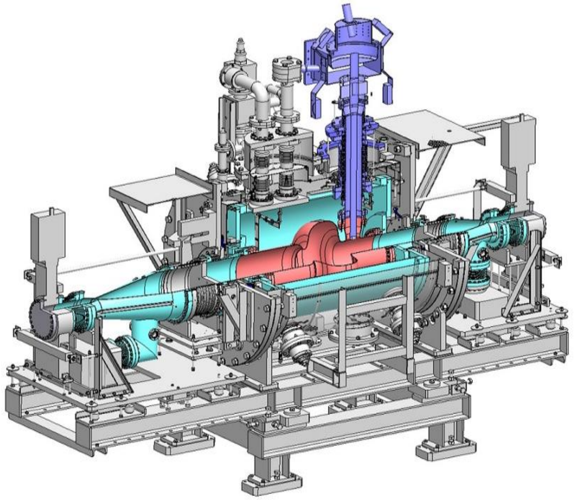


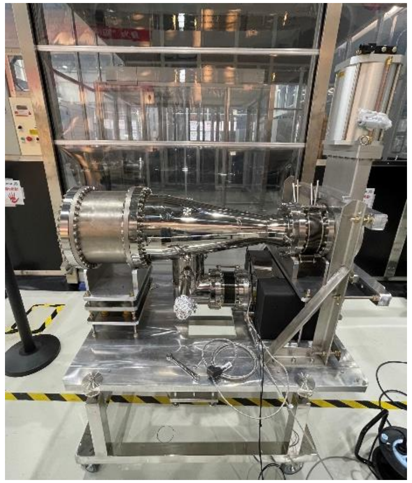
TABLE V
BUCKLING PERFORMANCE OF THE CAVITY UNDER TWO DIFFERENT BOUNDARIES

	Conditions	Φ (Bare)	Φ (Stiff.)	Φ_{cr}
Cell (LBP side)	BPs fixed	29.3	83.7	16.1
	LBP LF	10.5	30.2	
Cell (SBP side)	BPs fixed	29.4	85.1	16.1
	LBP LF	12.8	36.9	
LBP tube	BPs fixed	33.2	33.2	2.5
	LBP LF	17.2	31.0	

"BPs fixed" stands for both beam pipes are fixed, "LBP LF" stands for the cavity LBP side is free to move longitudinally while the SBP side is fixed, "Bare" stands for bare cavity without any stiffening rings, and "Stiff." stands for cavities with one pair of stiffening rings added on the cell.

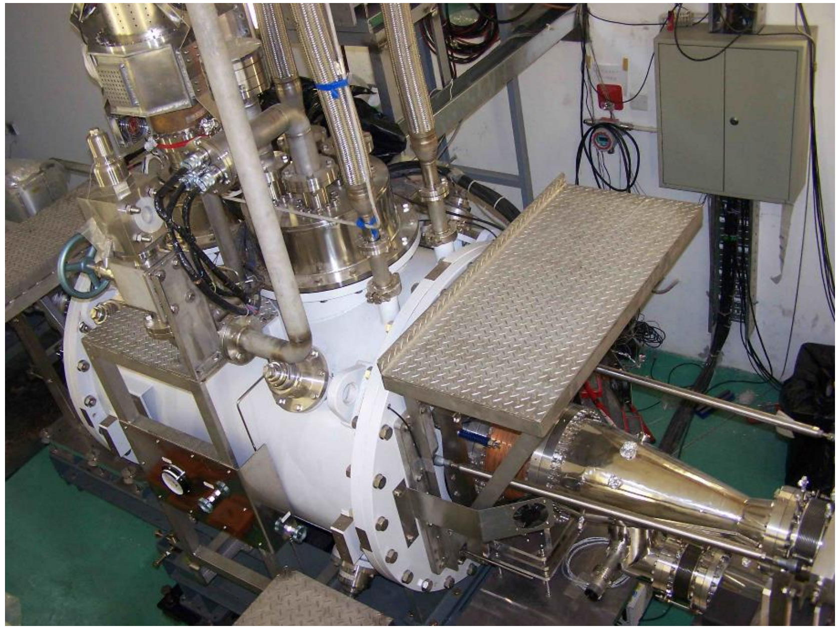


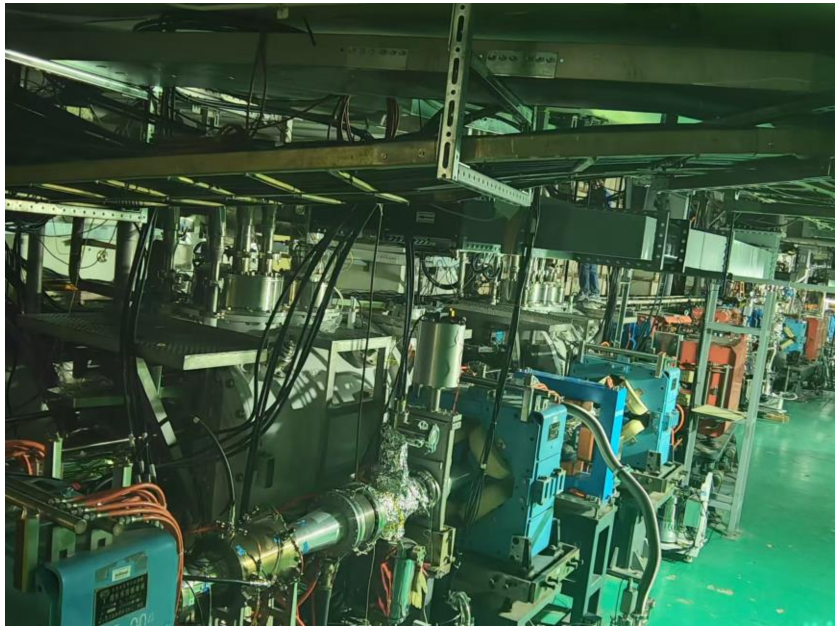




500 MHz KEKB-type single-cell SC cavity module

BEPCII-U 500 MHz Cavity and Cryomodule





- Two 500MHz superconducting cryomodule online operation
- Another two cryomodules have been installed in the tunnel for the upgrade of BEPC-Ⅱ
- The cavity related construction of BEPCⅡ-U have been finished and waiting for the cool down and beam commissioning

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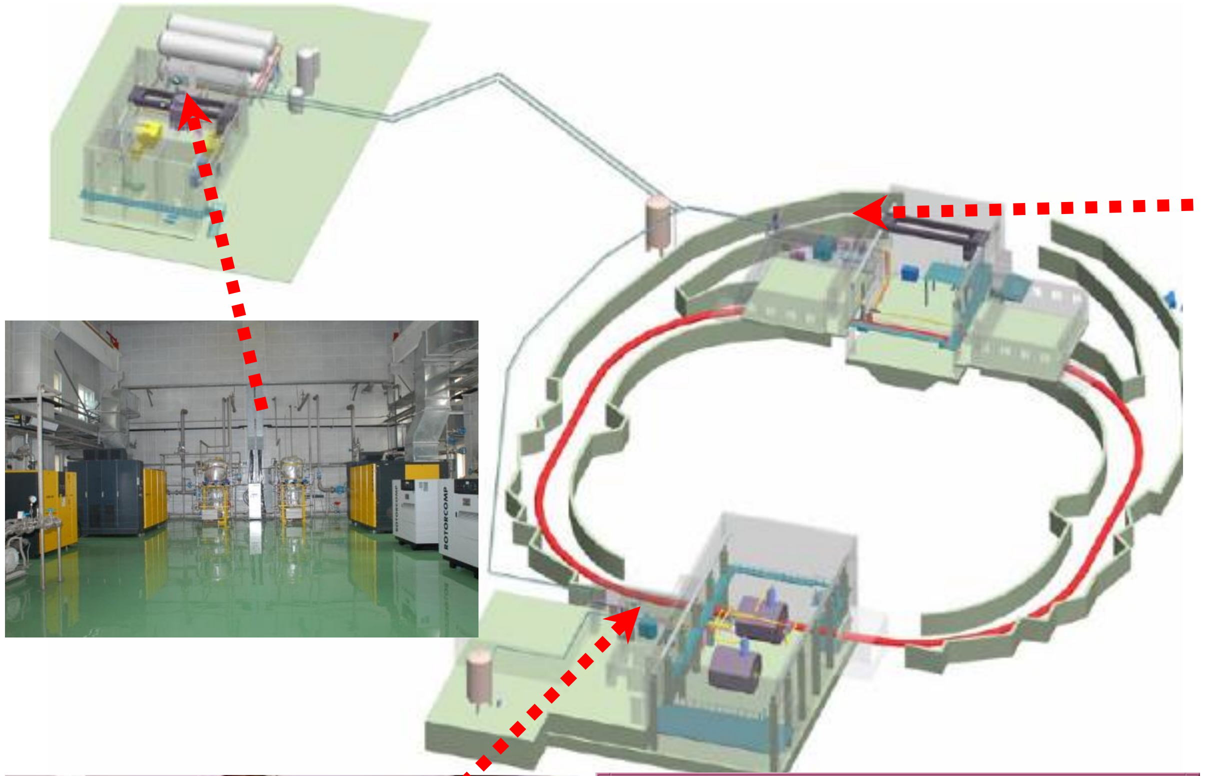
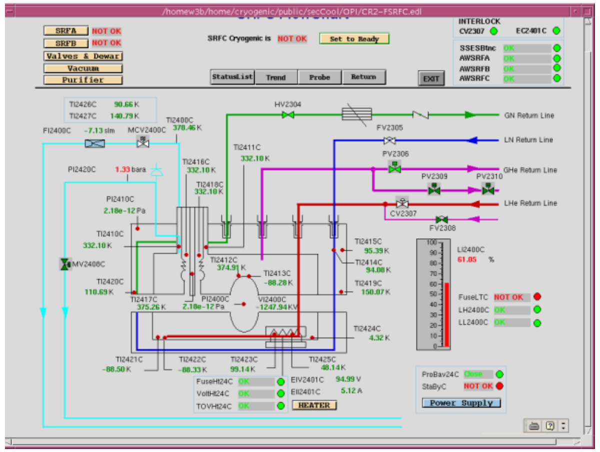
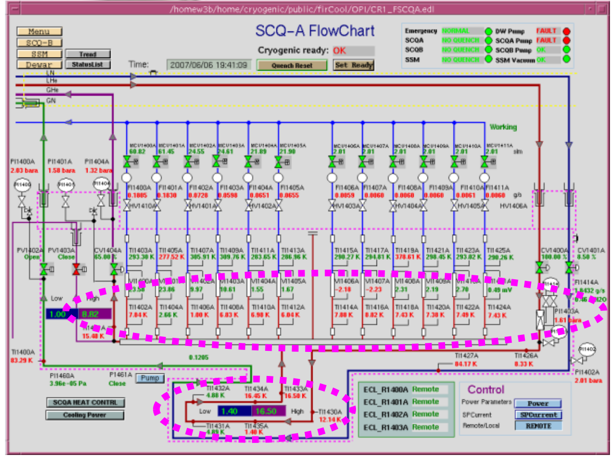
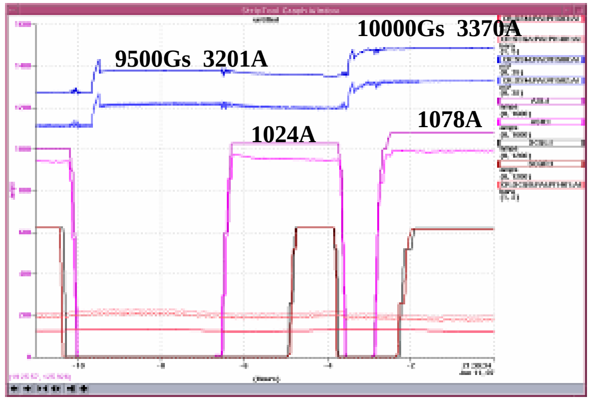
BEPCII cryogenic system

- Two parallel 500W@4.5k cryogenic system
- One system for the SRF with two 500MHz super conducting cavities
- The other system for the superconducting magnets in the collide point
- **BEPCII-U cavity side cooling capacity increased to 1kW@4.5K**



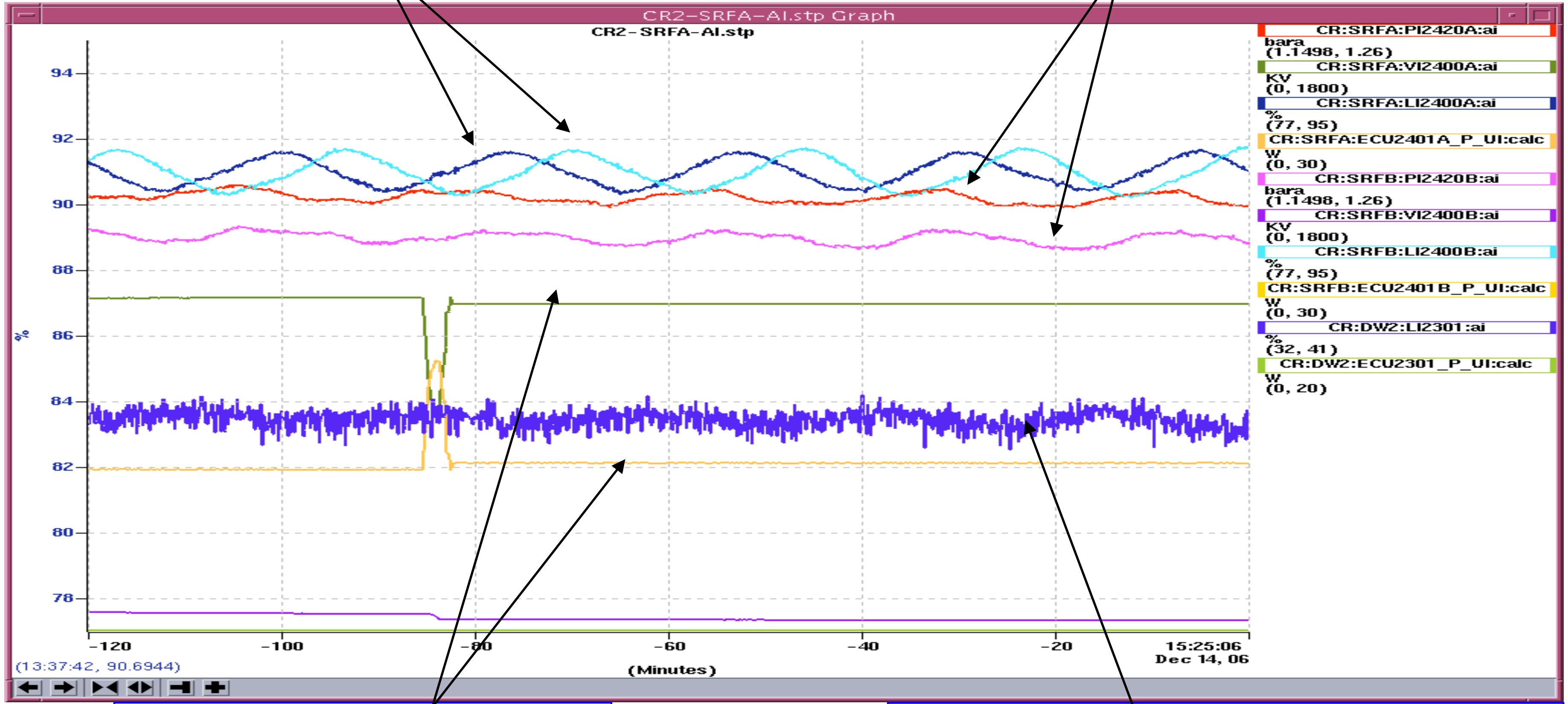






BEPCII SRF cryogenic system operation

Helium liquid level ± 1%

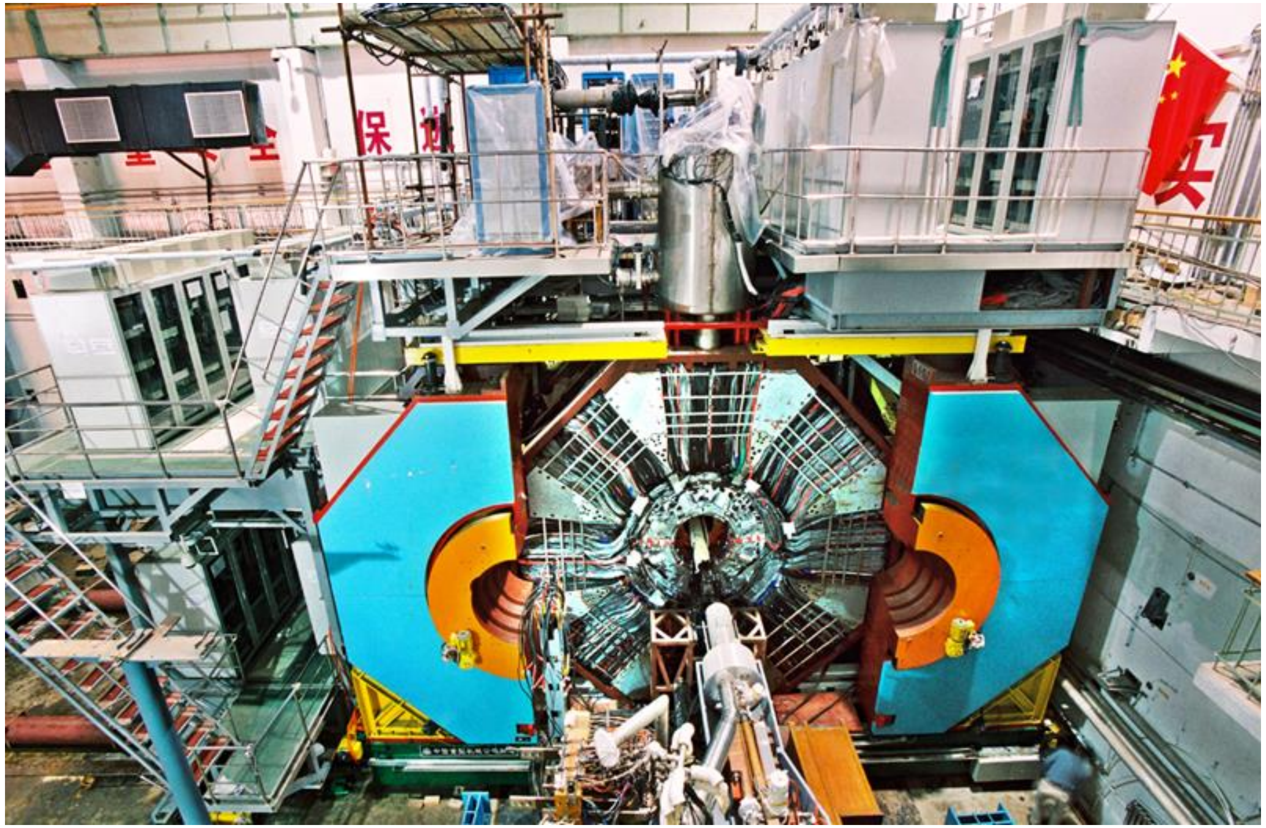
Helium pressure ± 3mbar



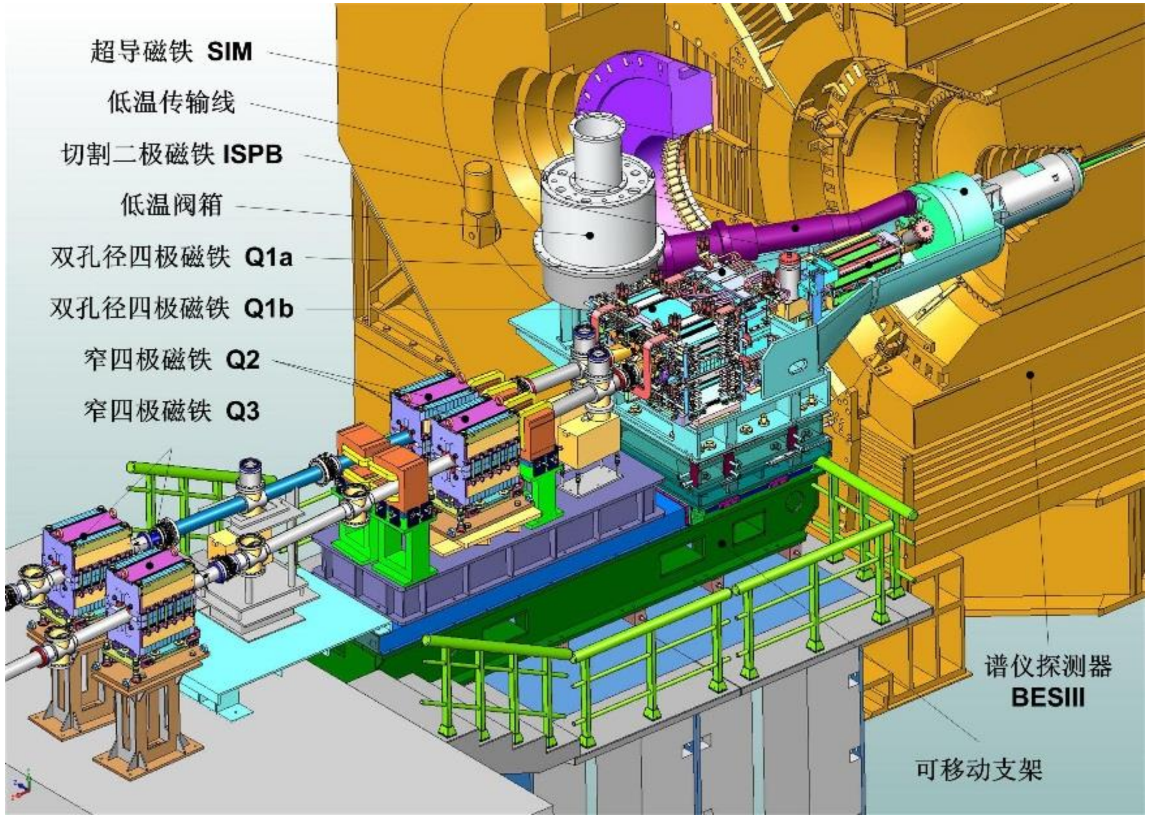
Heater power and RF power

Helium liquid level in 2000L Dewar

BEPCII superconducting magnet



BES III detector superconducting magnet



- Two super conducting insert magnets
- **Two new designed SC magnets have past test and installed in the tunnel for the upgrade of BEPC-II**
- The system cool down is undergoing from 1st March 2025

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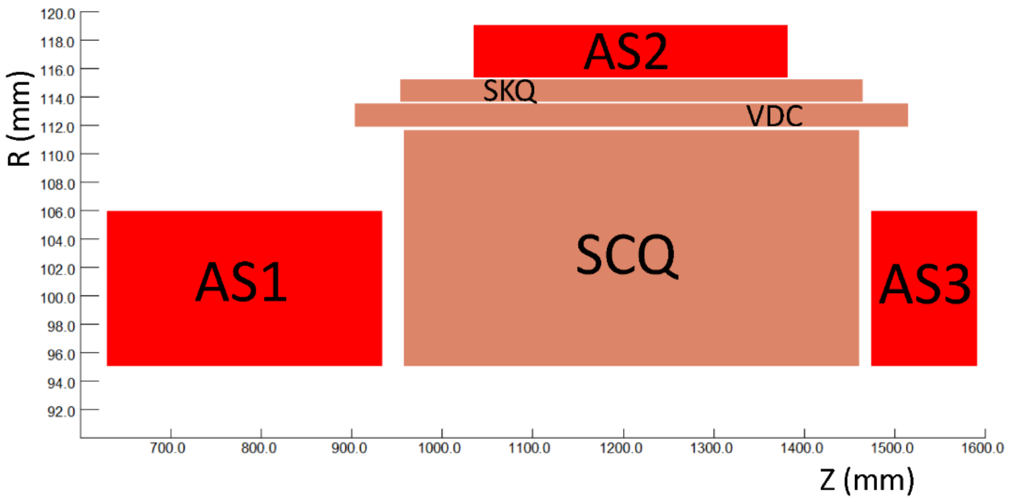
BEPCII-U IR SC magnets development

- BEPCII upgrade project (BEPCII-U) started in 2021,Maximum beam energy increased to 2.8 GeV
- Two multi-function SC magnets need to be developed; One SC magnet includes Quadrupole (SCQ), Anti-solenoid (AS1/2/3), Correctors: VDC, SKQ
- Magnet position, length and external dimensions are the same as BEPCII
- Main differences of BEPCII-U IR magnet, compared with BEPCII IR magnet

1. Maximum field gradient of SCQ is increased to 25T/m
2. Remove SCB coil (No synchrotron radiation mode in BEPCII-U)



Coil	Field strength	Position from IP (mm)	Effective length (mm)	Maximum Operation Current (A)
Anti-solenoid (1/2/3)	Max 2.85T	630-1590	-------	1130 AS2/3 need trim currents
SCQ	25T/m	961-1457	400	530
VDC	0.059T	904~1514	380	27
SKQ	0.937T/m	954-1464	400	47

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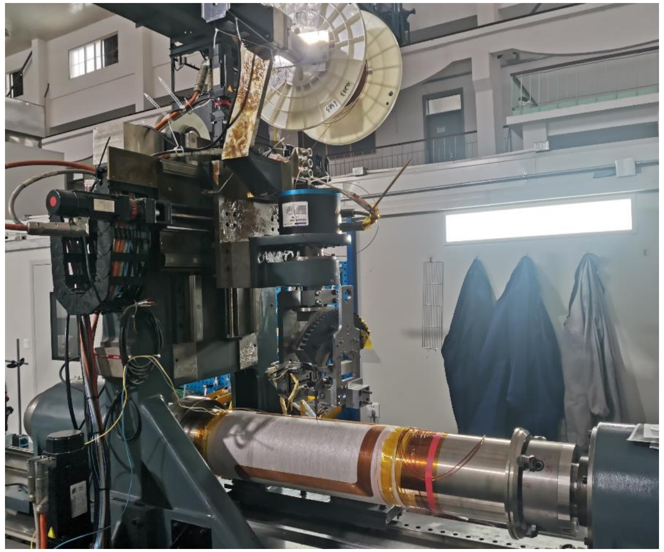
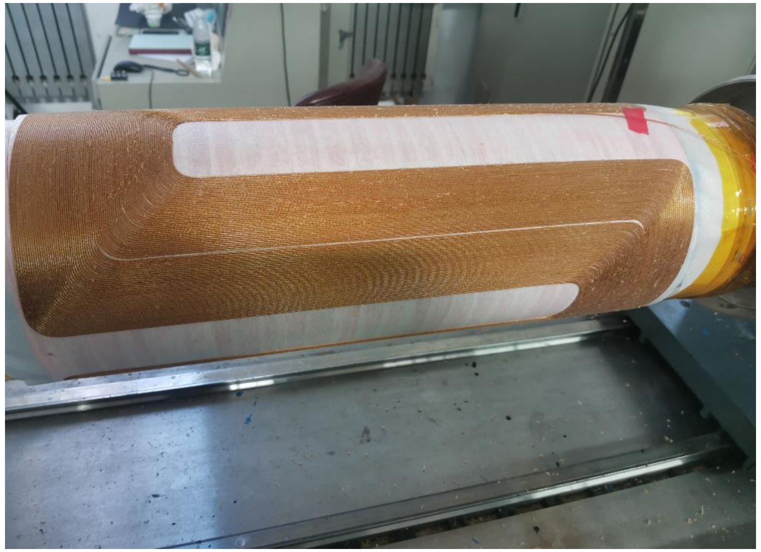
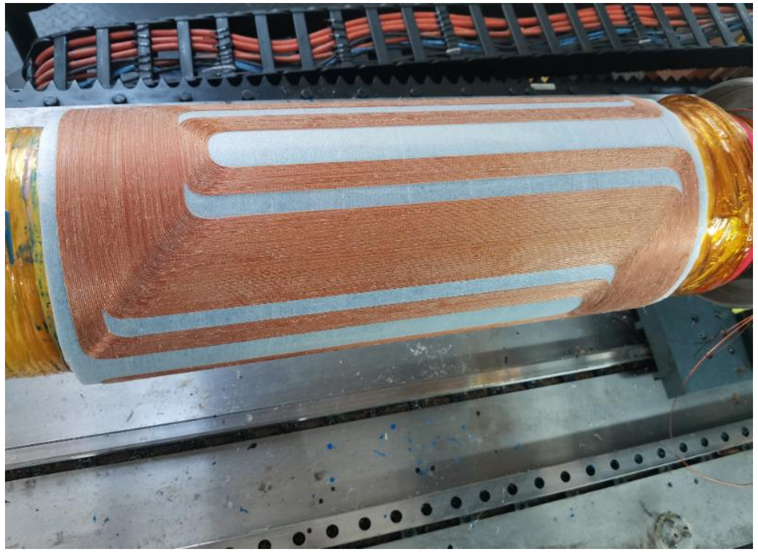
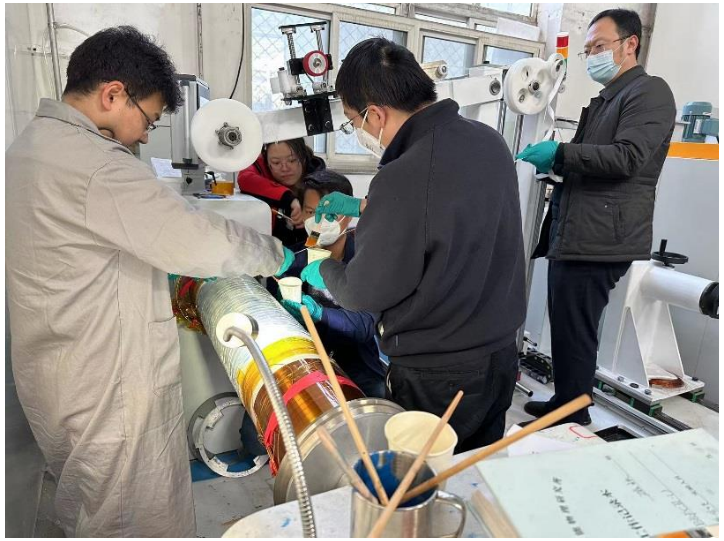
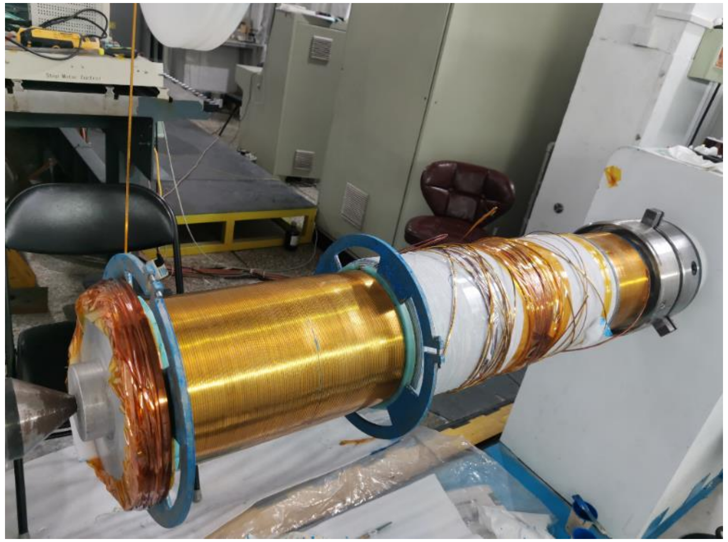
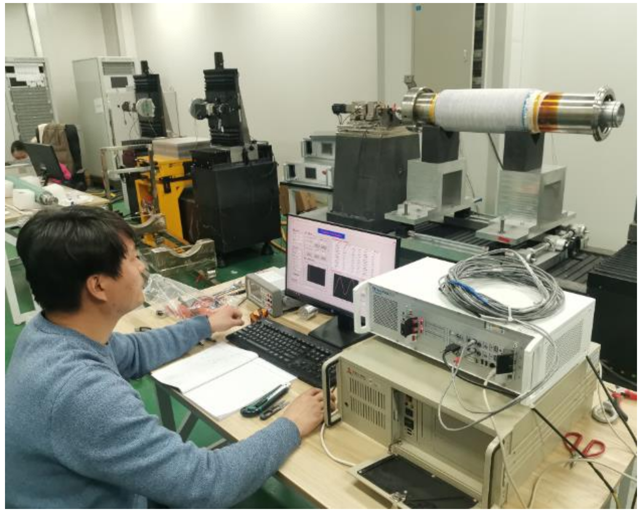
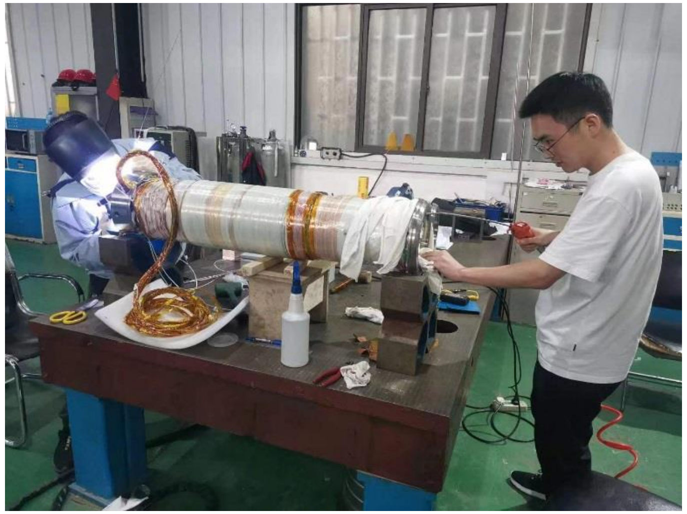
BEPCII-U IR SC magnets development

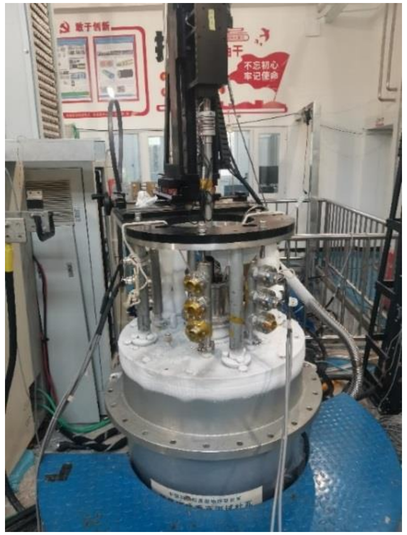




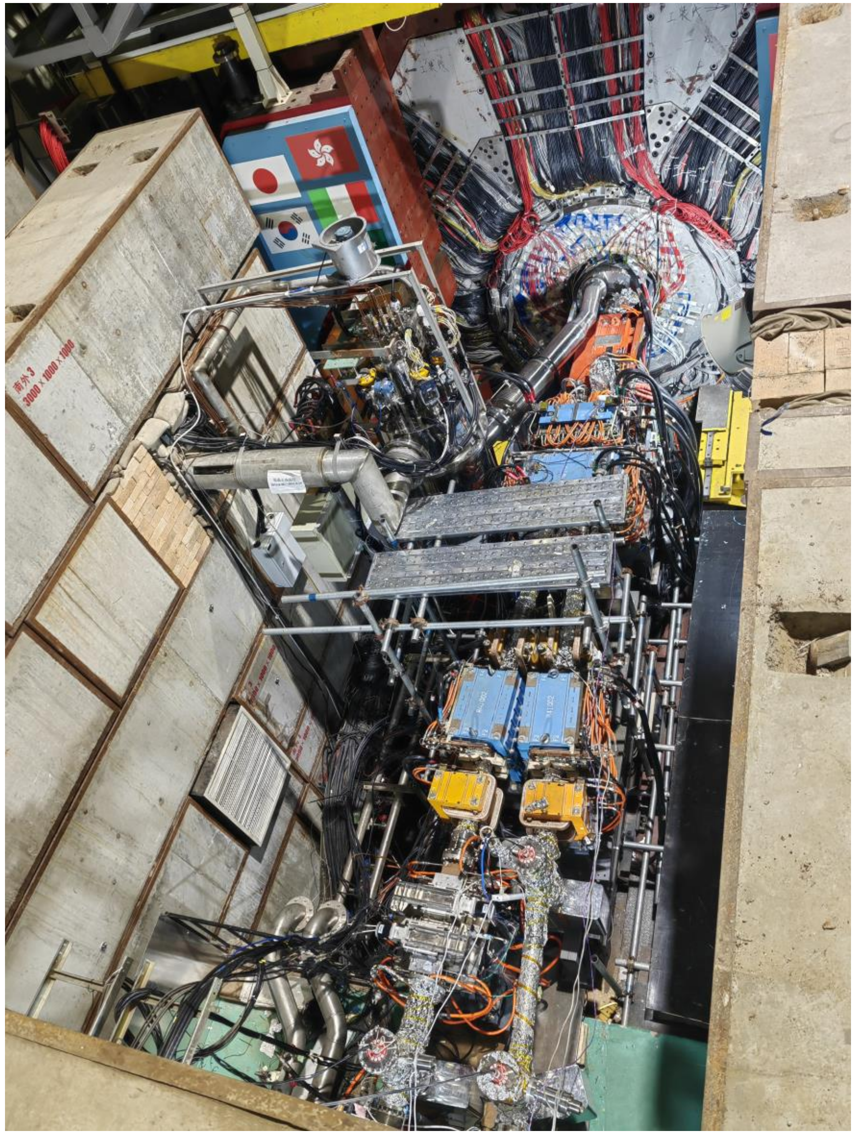
BEPCII-U IR SC magnets development







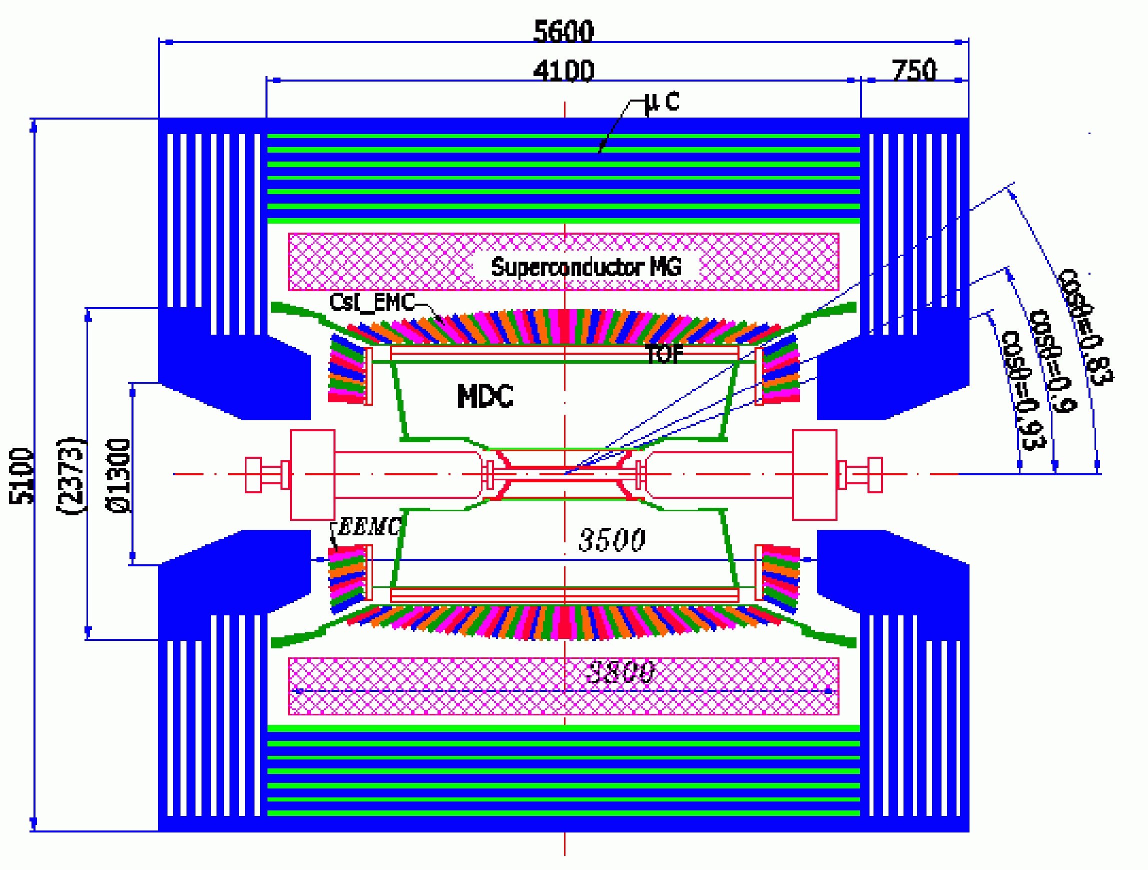
BEPCII new designed superconducting magnet



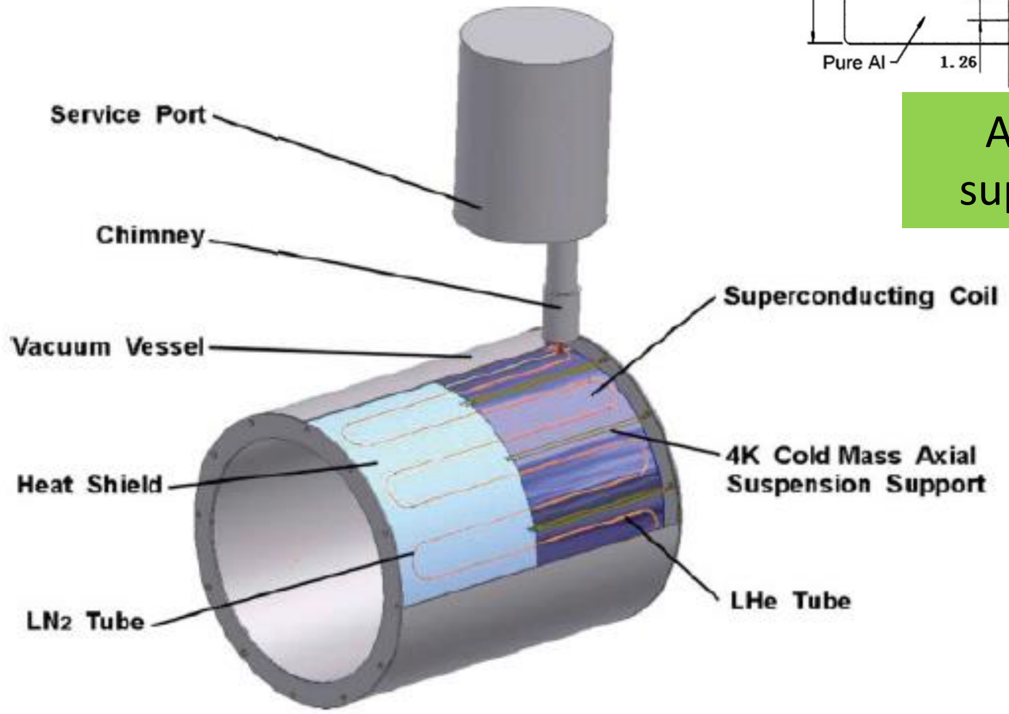
BESIII Detector magnet

The large superconducting solenoid magnet(SSM) of the detector serves as a key component of the large electron collider, providing a uniform and stable magnetic field for the detector.

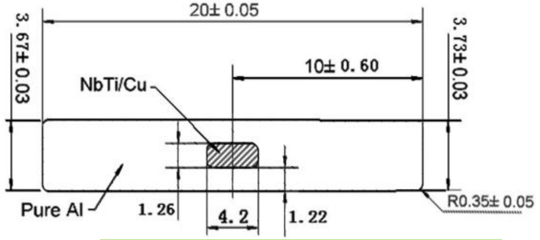
SSM is designed with cold bore of 3 m in diameter and 3.5 m in length and provides 1T magnetic field.



BESIII detector



The main structure of SSM

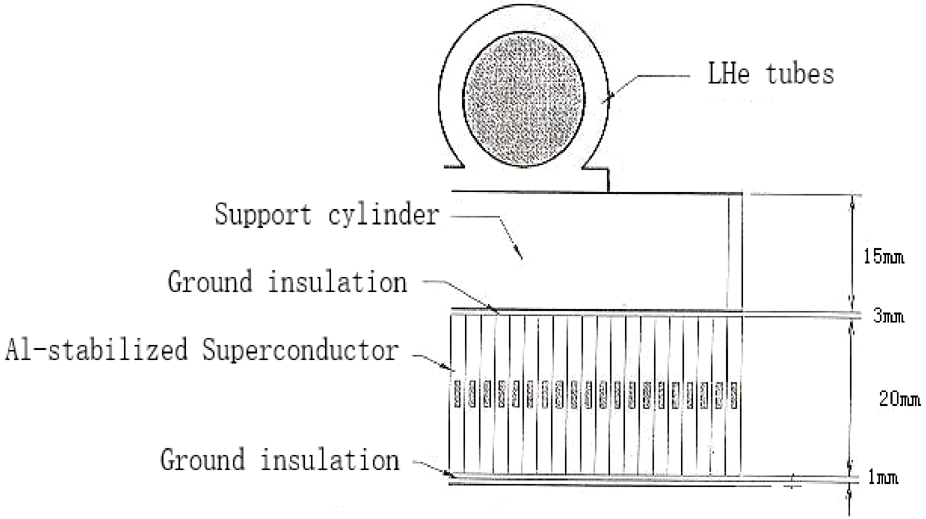


Al-stabilized supercondutor

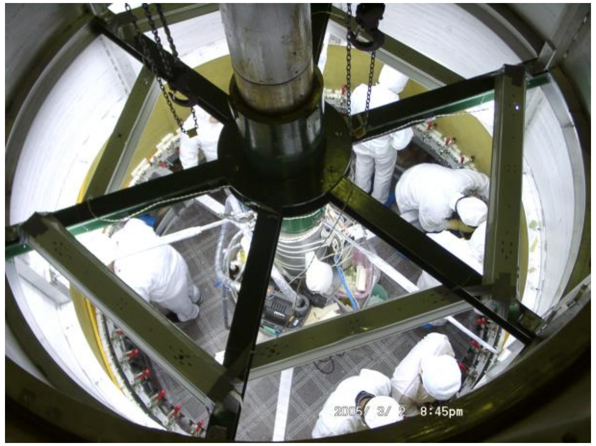
BESIII Detector magnet

Main parameters of the SSM

Items	Value
Central field	1.0 T
Uniformity in the tracking region	5%
Operating current	3600 A
Inductance	1.7 H
Stored energy	11 MJ
Winding structure	Single layer
Winding length	3532 mm
Winding mean radius	1490 mm
Total turns	850

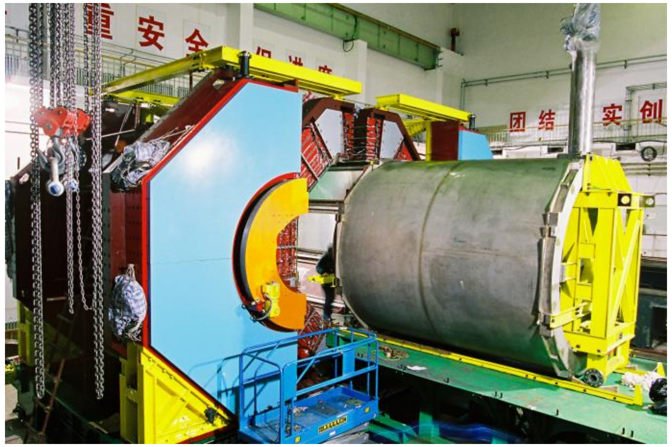


Structure of the coil cross-section

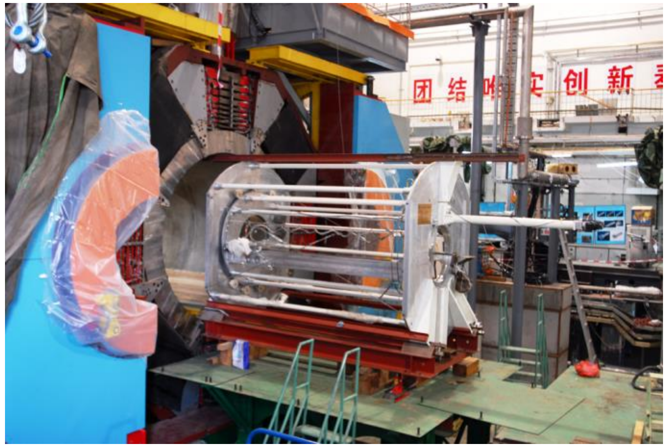


Inner-Winding of coil

Assembly



Insert to the detector



Field measurement

Operating status

- **Operating stably for nearly 20 years.**
- More than 40 quenches in total, caused by cryogenic failures, vacuum failures, power grid fluctuation, or other equipment failures.
- Improvements aimed at the aging problems.

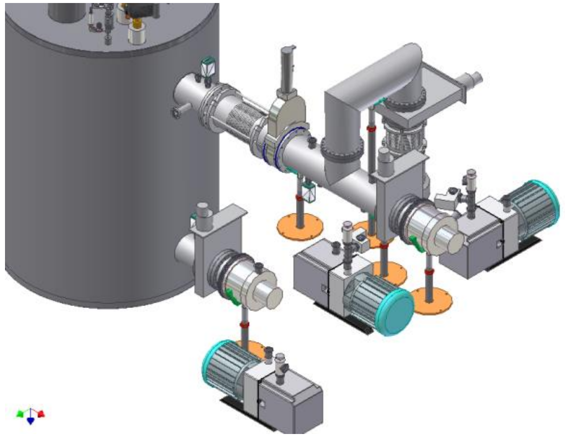
  Maintenance of the vacuum system;

  Replacement of the power supply;

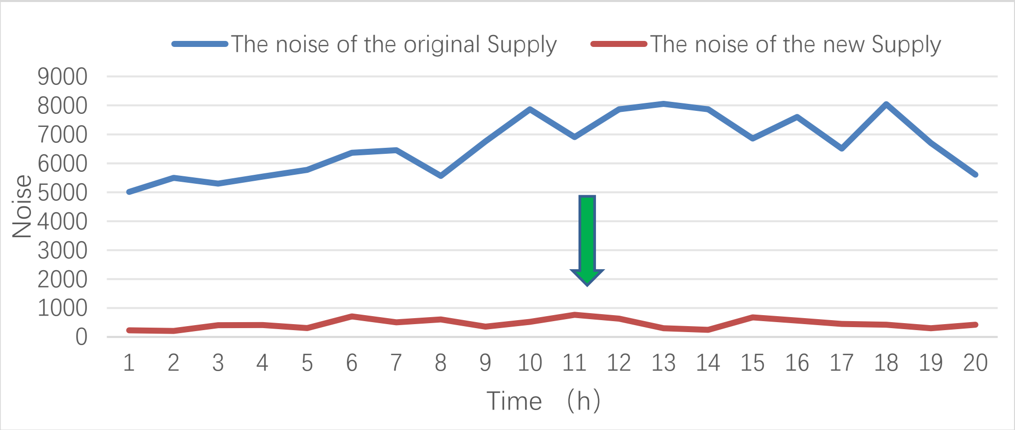
  Update of the quench protection system;

  Development of new valve box as spare parts.
- **Goal: Continue operating stably for another ten years.**

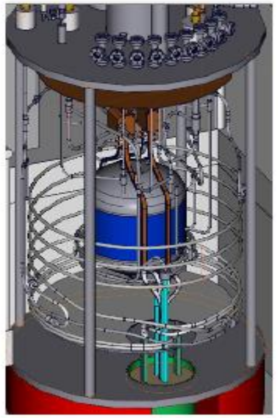
Reported by the "Xinwen Lianbo" of CCTV, 2006.9.19



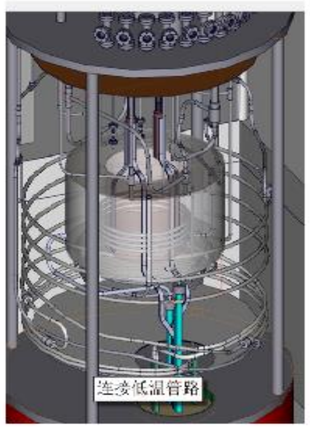
Vacuum system
(maintained at 2×10⁻² pa)



Noise level reduced by an order of magnitude
after the replacement of the Power supply

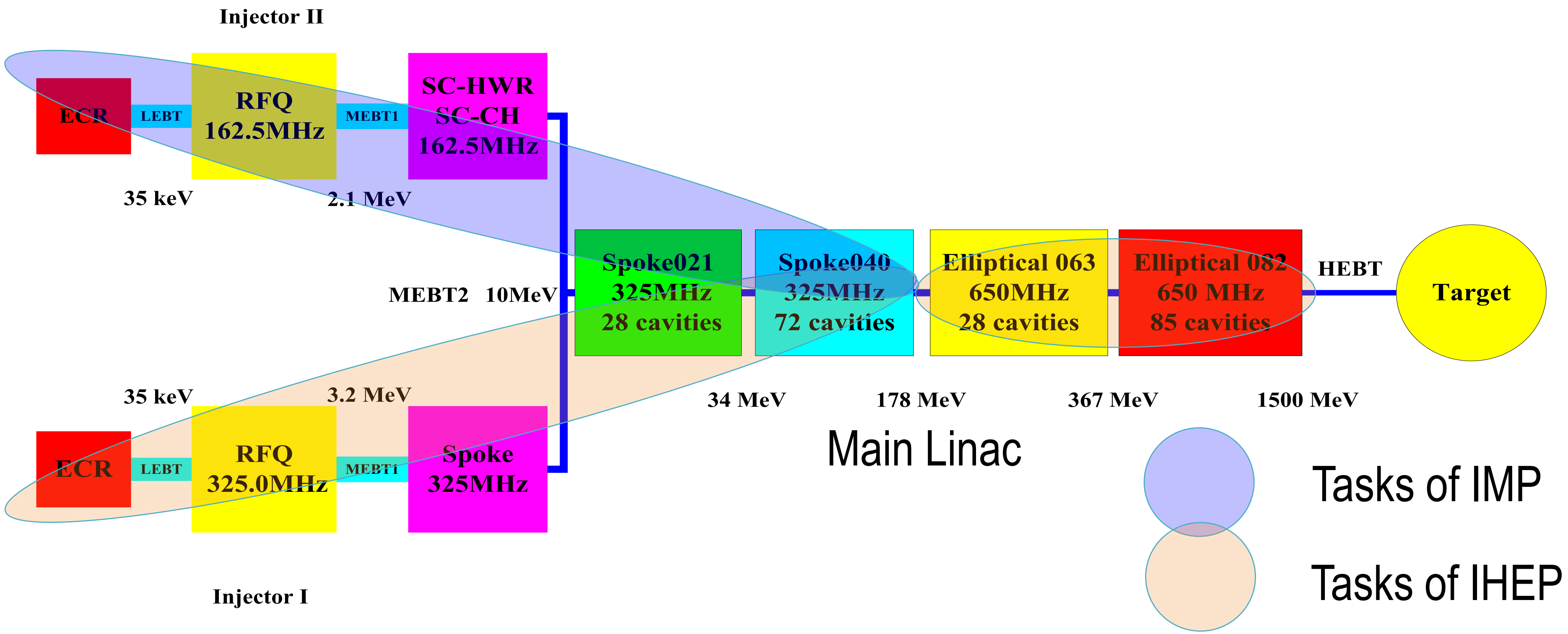


Current valve box



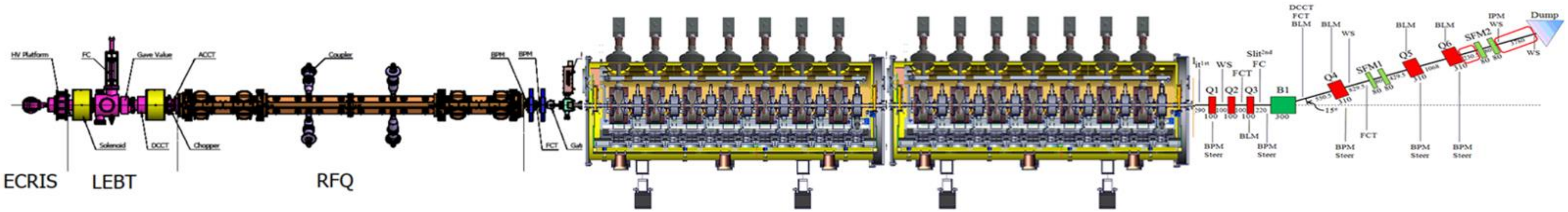
New valve box

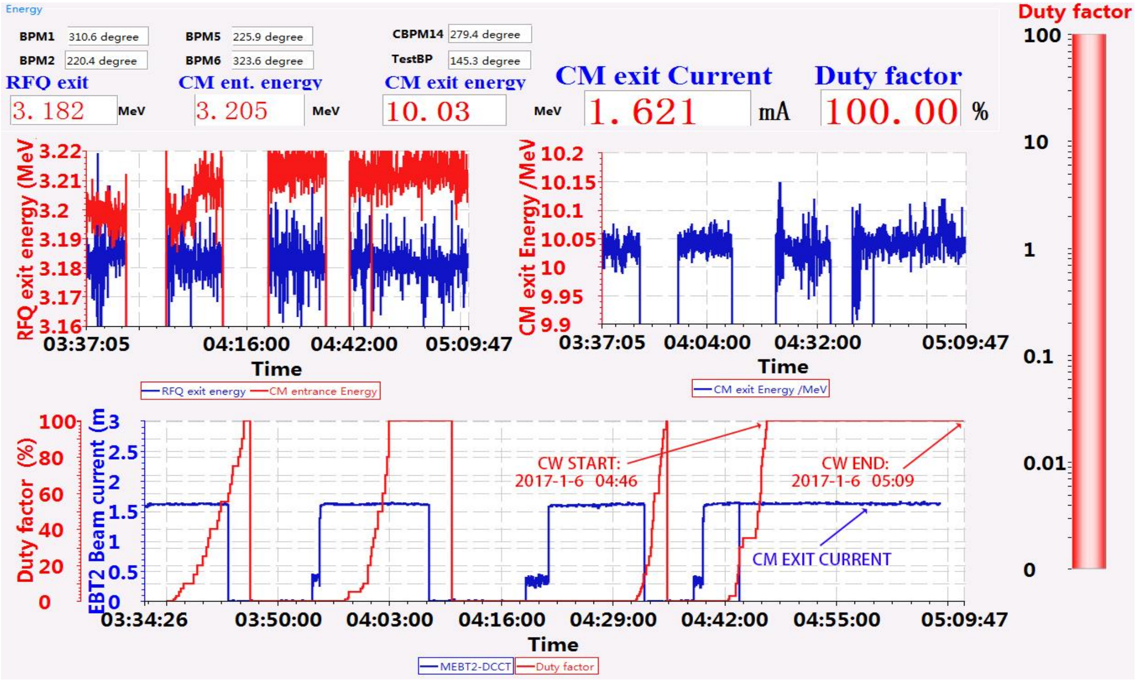
ADS Injector I



- 2011-2017 "Strategic Priority Research Program of the Chinese Academy of Science""Accelerator Drive Subcritical System（ADS）"
- The task is undertaken by two institutes IMP and IHEP
- The first time several superconducting cavities and magnets integrated in one cryomodule, which lays the foundation for the future large scale superconducting accelerators
- Now the new CiADS project in under construction in IMP Huizhou campus

IHEP ADS Injector SRF System





14 spoke012 cavities accelerate 2 mA CW proton beam to 10 MeV in Injector-I at IHEP.

6 spoke021 cavities increase CW proton beam to 25 MeV in Injector-II at IMP.

ADS Injector SRF System

- Batch production of Spoke012 and Spoke021, meet spec
- SSR024/040, HWR325, MB082 prototypes

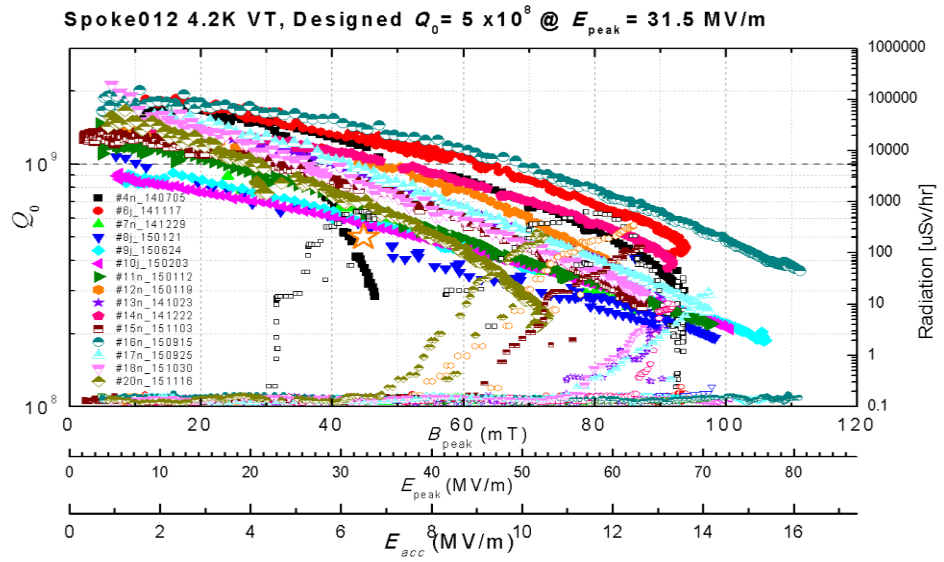
Spoke012 cavity string

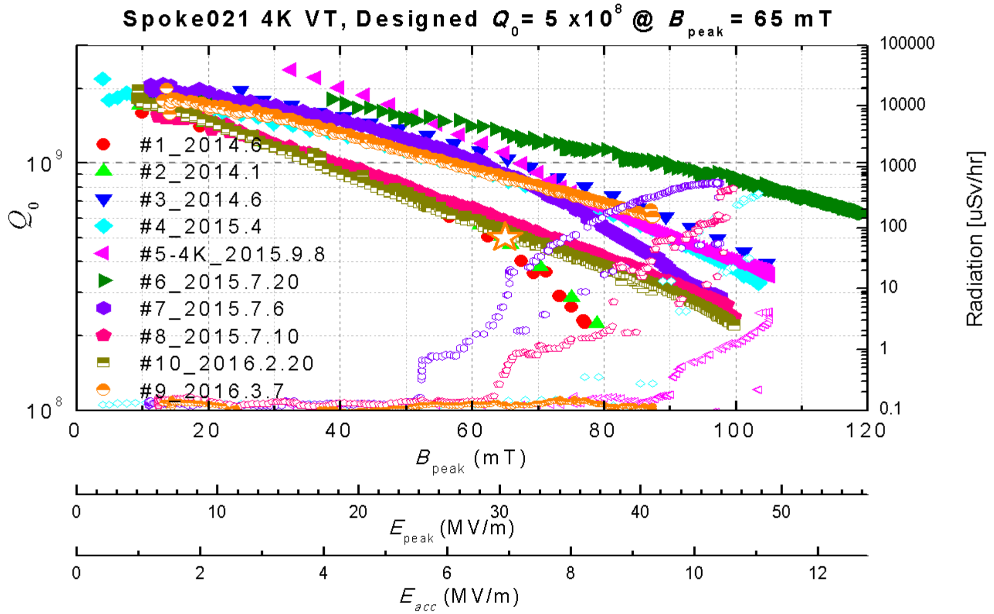
650 MHz 5-cell cavity (beta 0.82)

325 MHz Spoke cavity (beta 0.21)

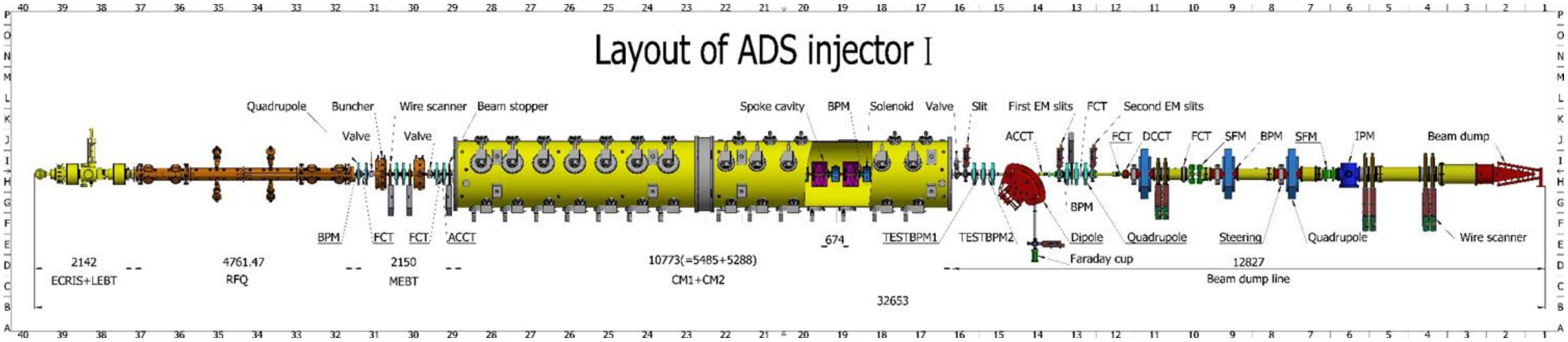
325 MHz Spoke cavity (beta 0.40)

325 MHz HWR cavity (beta 0.14)





ADS Injector Ⅰ 2K superfluid helium cryogenic system



- 2 cryomodules, each with 7 superconducting spoke cavities and 7 superconducting solenoid magnets
- 4K/2K cryogenic system
- Refrigeration capacity 1000W@4.5K
- 100W@2K for cryomodules, 100W@2K for test station
- Pressure fluctuation@2K inside cavity helium vessel is not more than ±10Pa
- Vertical and horizontal test station
- The first self design hundred watts 2K super flow helium system

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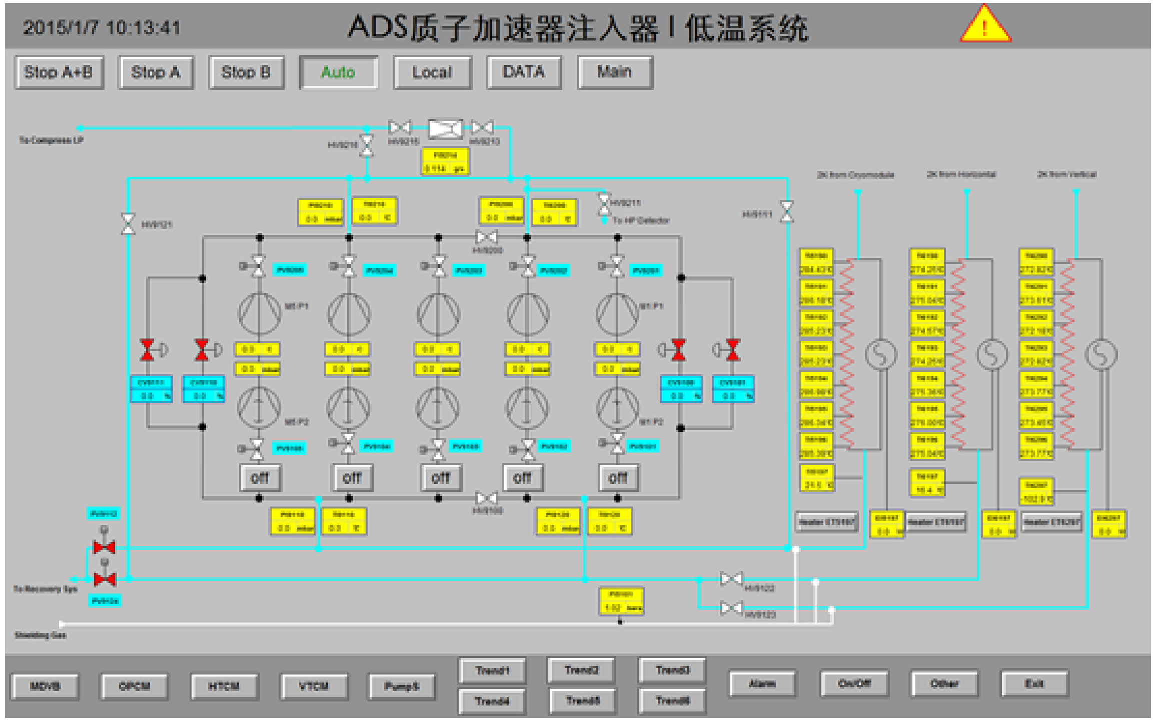
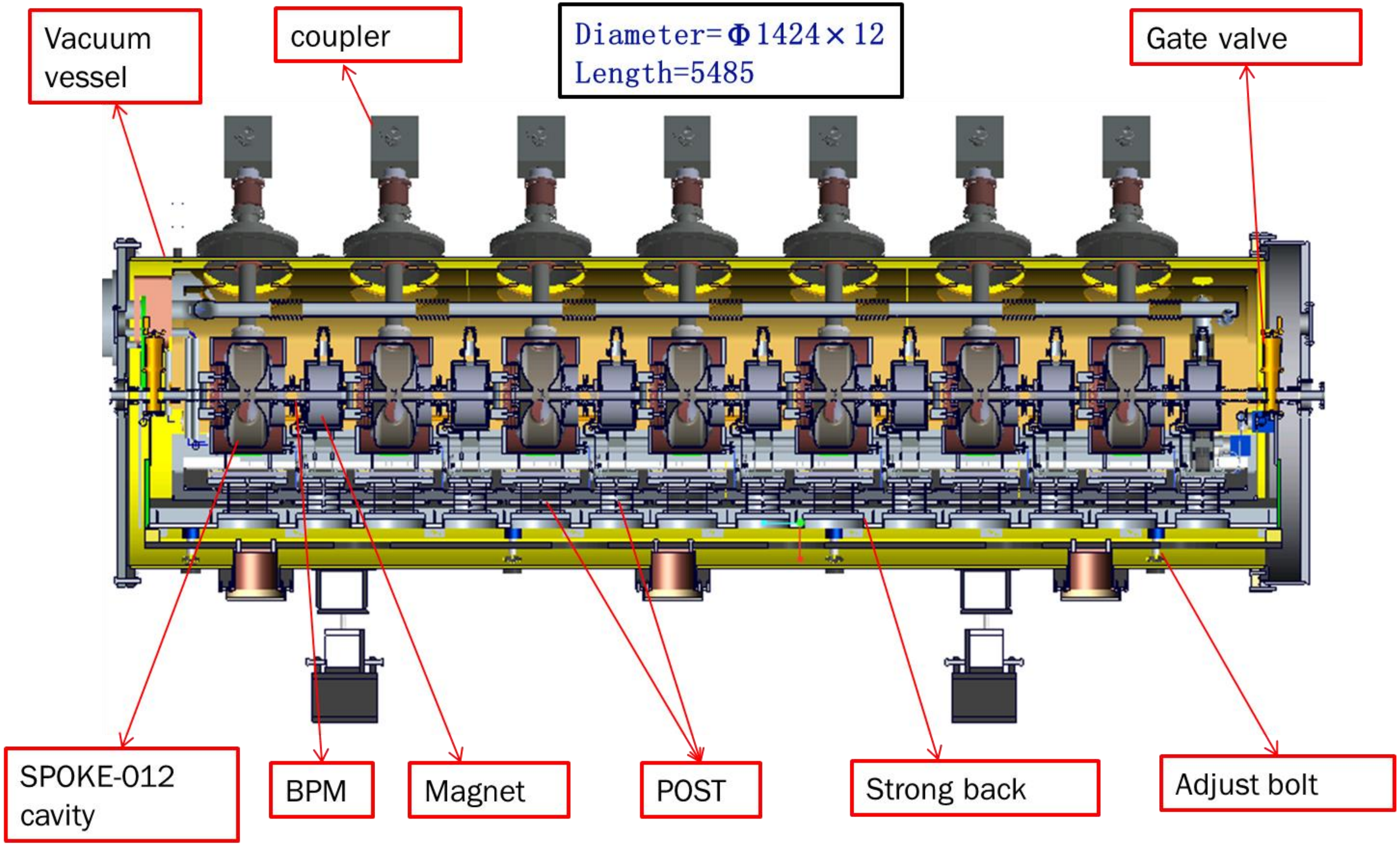
2K pumping system



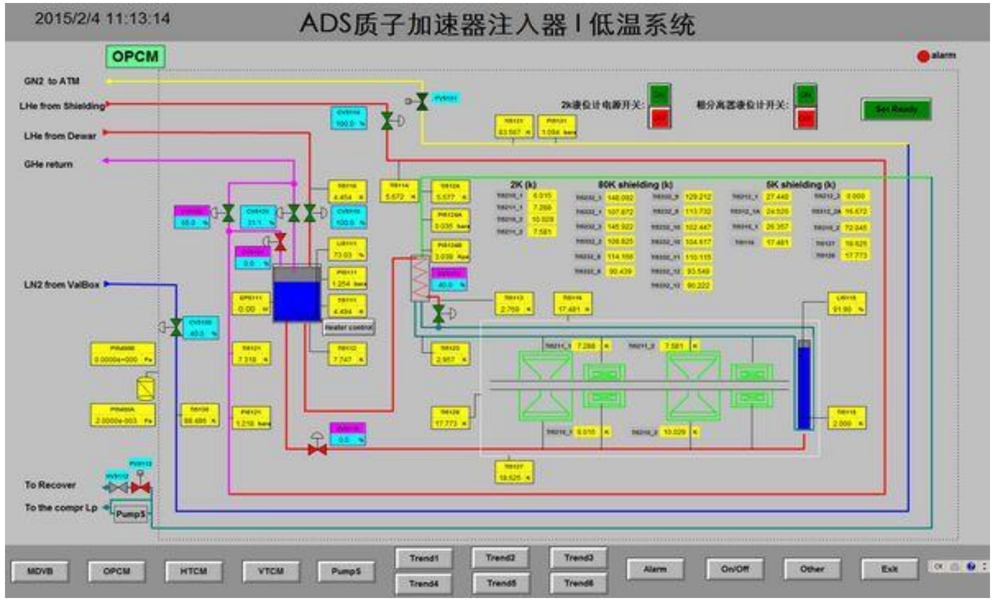
- The total capacity 8000m^3/h
- 3 sets for the cryomodules
- 2 sets for the test stations

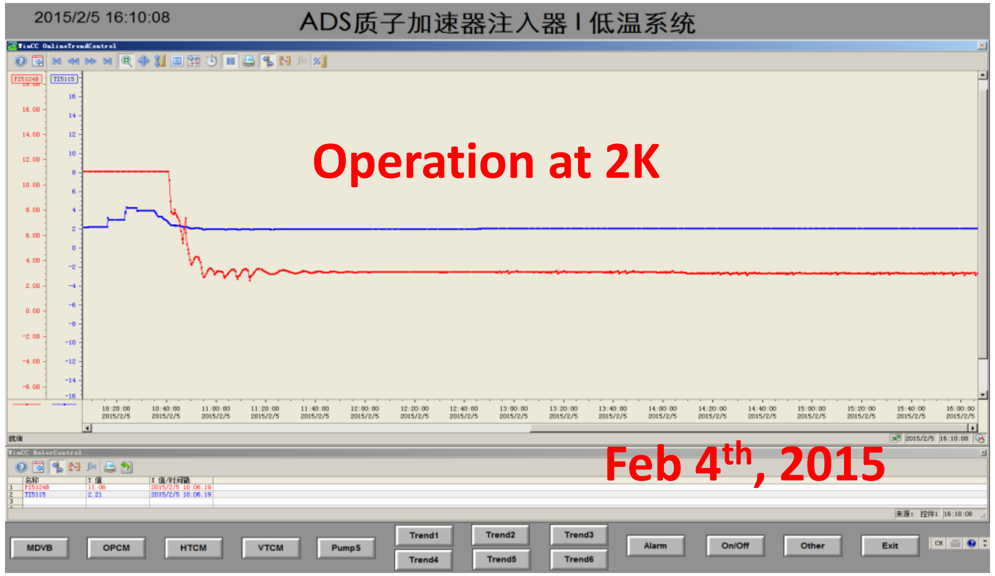
29

ADS Spoke cavity cryomodule

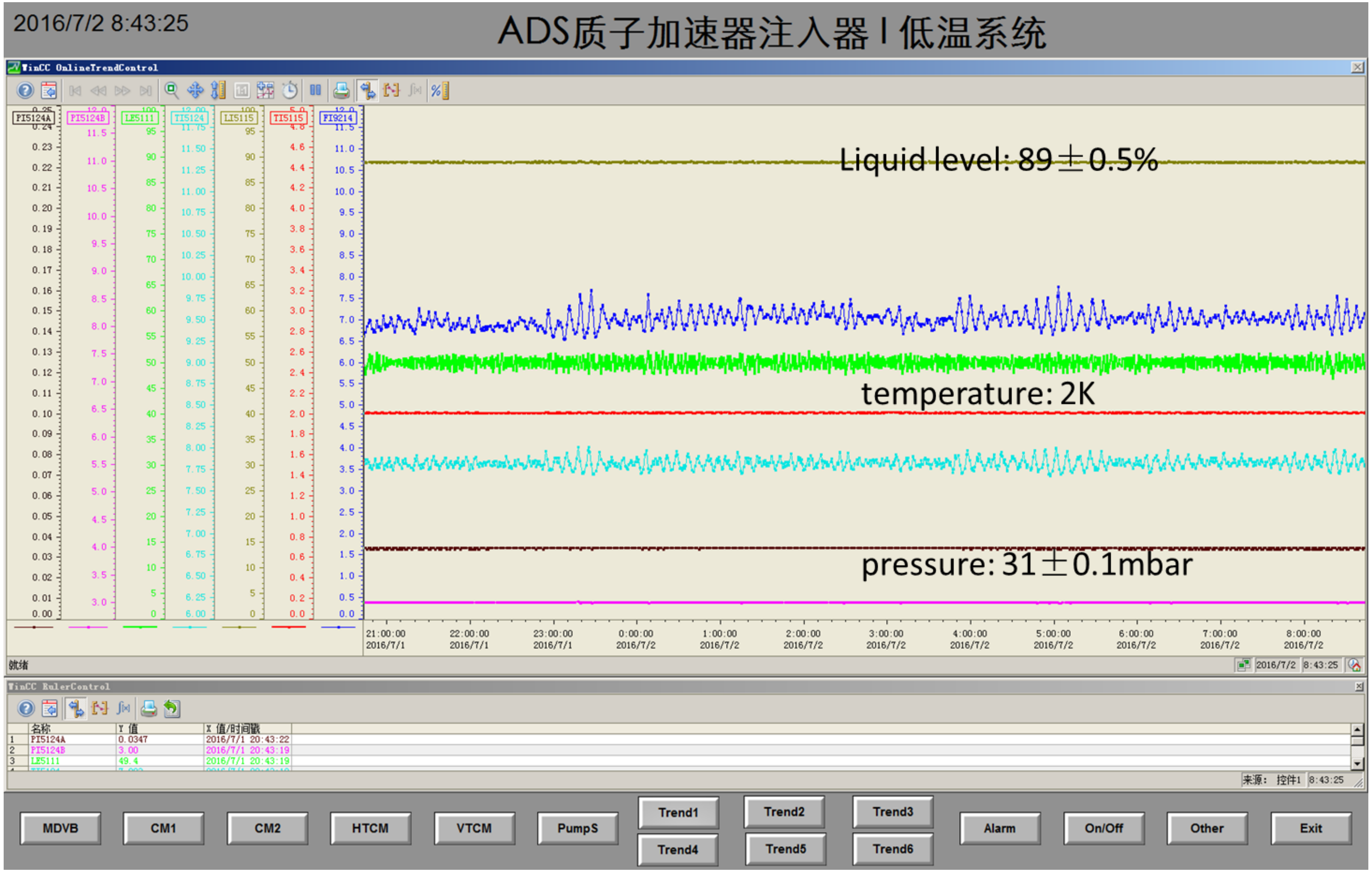


ADS project first realization of 2K superfluid helium





ADS Injector Ⅰ 2K cryogenic system stable operation



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IHEP HEPS

高能同步辐射光源

(HEPS | High Energy Photon Source)

建设内容：加速器、光束线站、配套土建工程及辅助设施等;

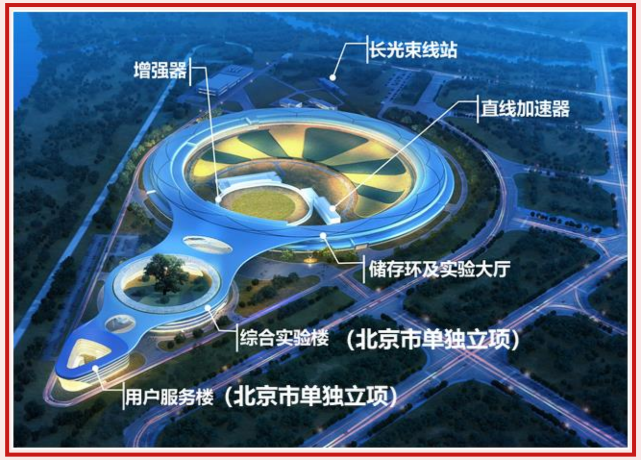
工　　期：6.5年，2019年7月-2025年12月;

法人单位：中科院高能物理研究所;

建设地点：北京怀柔科学城北部核心区；

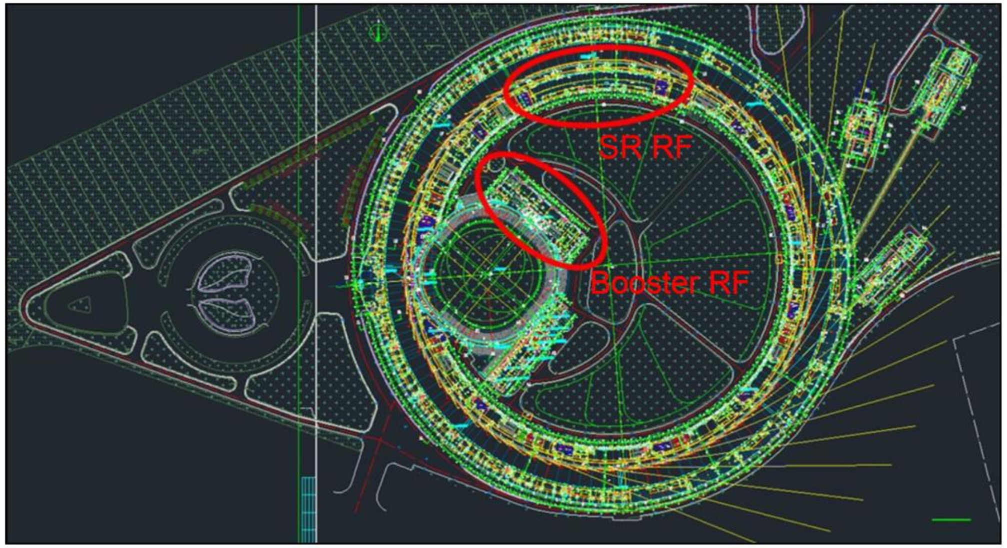
占地面积：976亩；

建筑面积：12.5万平米。

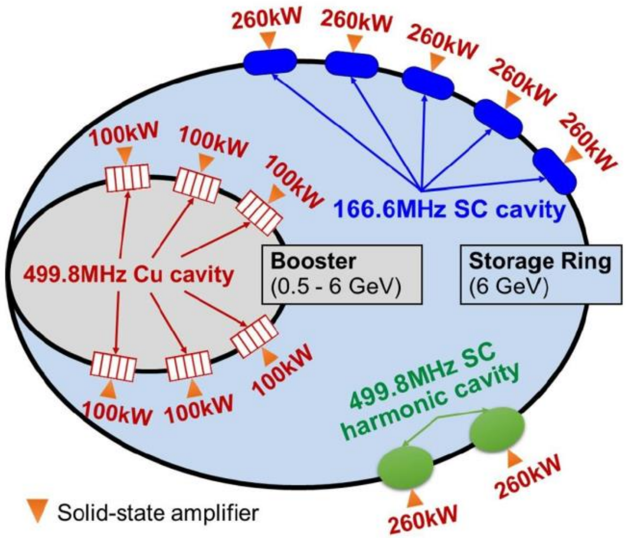


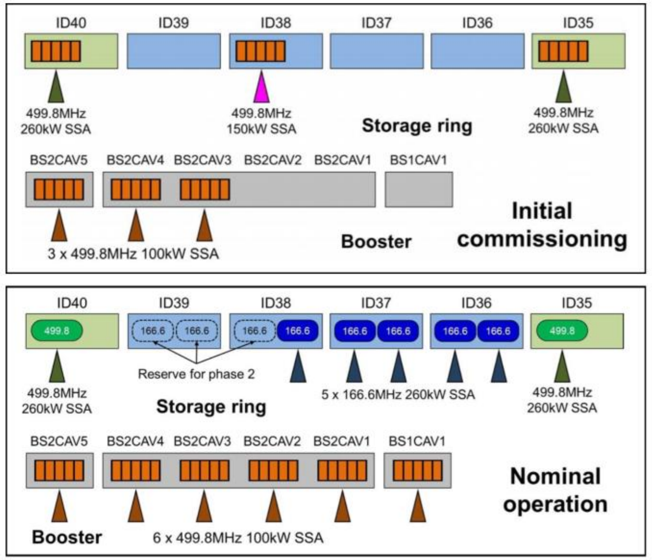
Main parameters	Value	Main parameters	Value
Beam energy	6 GeV	Emittance	< 60 pm·rad
Circumference	1360.4 m	Brightness	$>10^{22}$

HEPS RF System



Parameter	Value	Unit
Beam energy	6	GeV
Circumference	1360.4	m
Beam current	200	mA
Lattice type	7BA	-
Number of sectors	48	-
Natural emittance	34.2	pm·rad
Natural bunch length	5.06	mm
Energy loss (bare lattice)	2.64	MeV
Total no. of IDs (Phase I)	14	-
Total beam power	850	kW
Radiation damping time (x/y/z)	10.85/20.62/18.76	ms
RF frequency (main, 3rd harm.)	166.6, 499.8	MHz
Main RF voltage (w/ harm. cav.)	5.16	MV

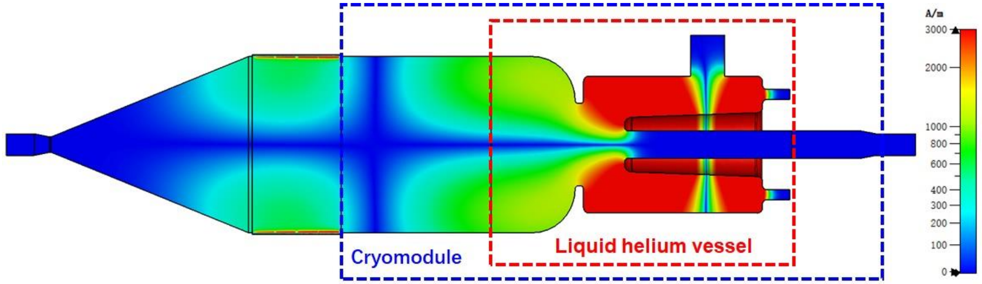


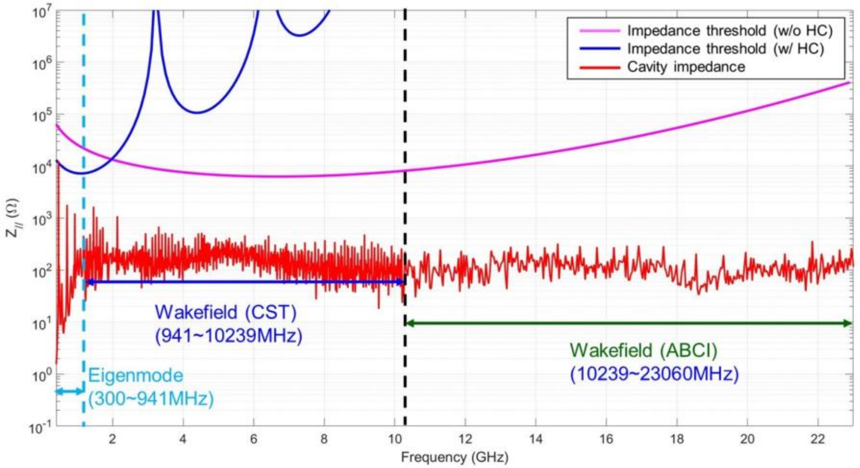


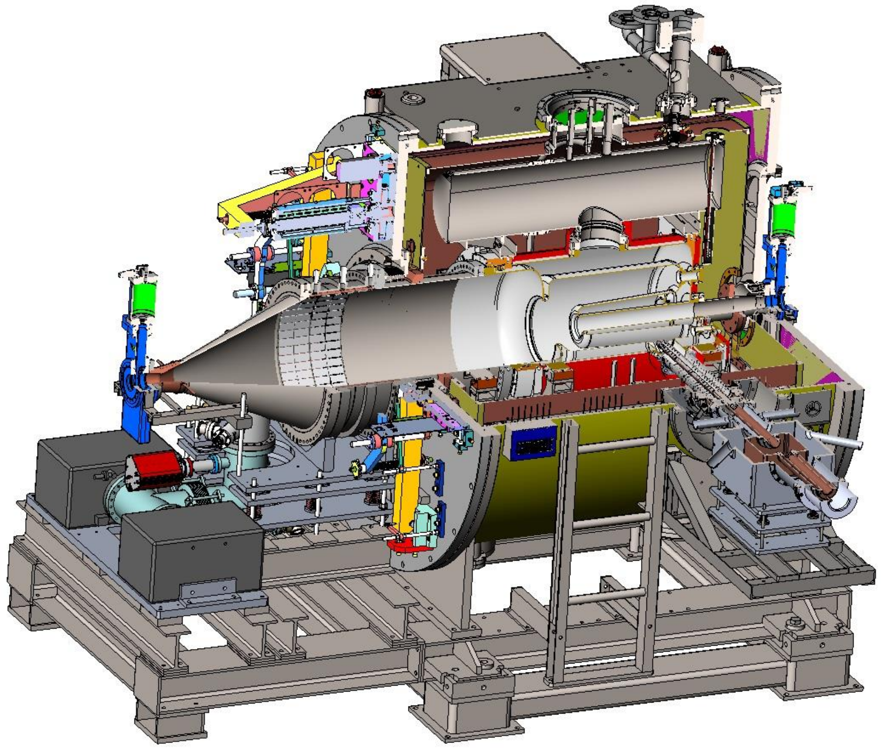
Parameter	Value	Unit
Circumference	1360.4	m
RF frequency (f_0)	166.6	MHz
Total energy loss per turn (U_0)	4.14	MeV
Total beam power (P_b)	850	kW
Total RF voltage (V_{RF})	5.16	MV
Number of main RF cavities	5	-
RF power per main cavity	170	kW
Cavity type	SRF cavity	-
HOM control	Heavy damping	-
Harmonic RF frequency (f_{HC})	499.8	MHz
Number of RF stations	5 + 2	-
Transmitter power per RF station	260	kW
Field noise (pk-pk)	±0.1%, ±0.1°	-

IHEP HEPS 166 MHz Cavity and Cryomodule

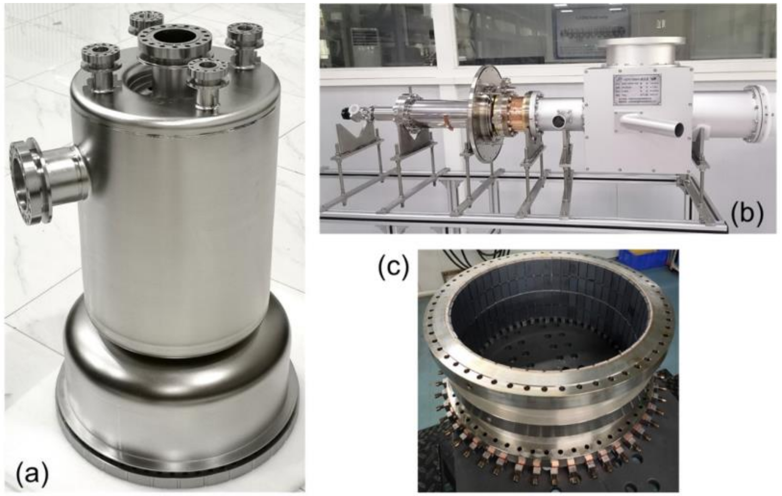
- Low frequency: 166.6 MHz, β=1
- High RF power: 180 kW per cavity
- High current: 200 mA → heavy HOM damping: $Q_L < 1000$
- Compactness: limited space of the straight section (6 m for 2 cavs)
- Stable operation (user facility): large margin in RF parameters

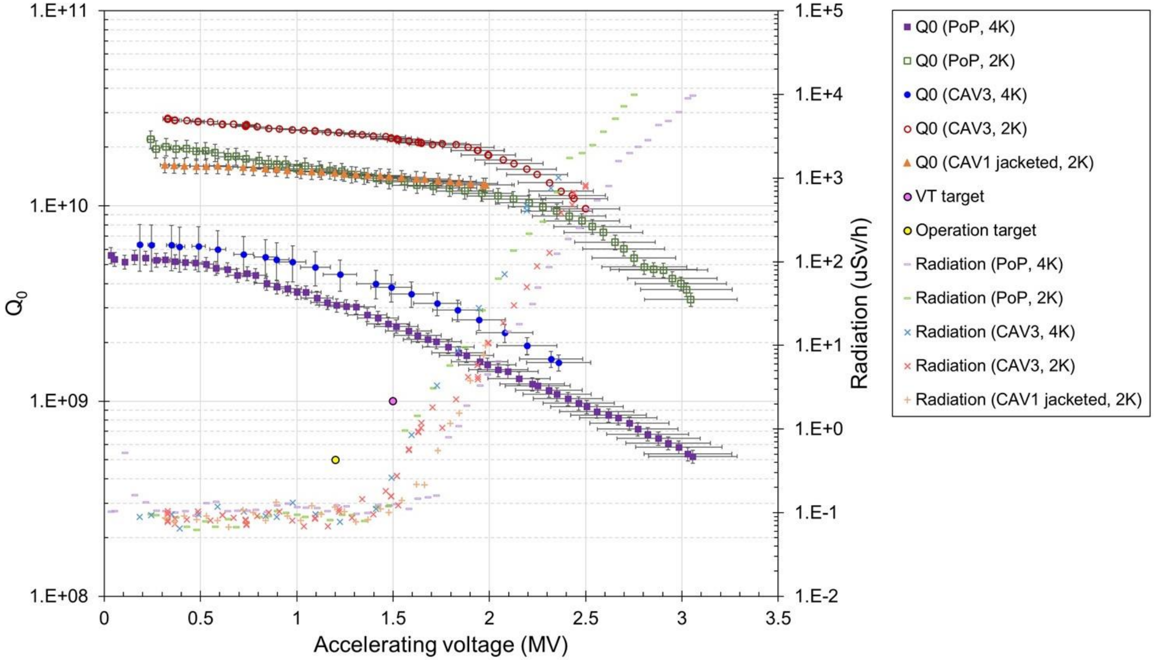




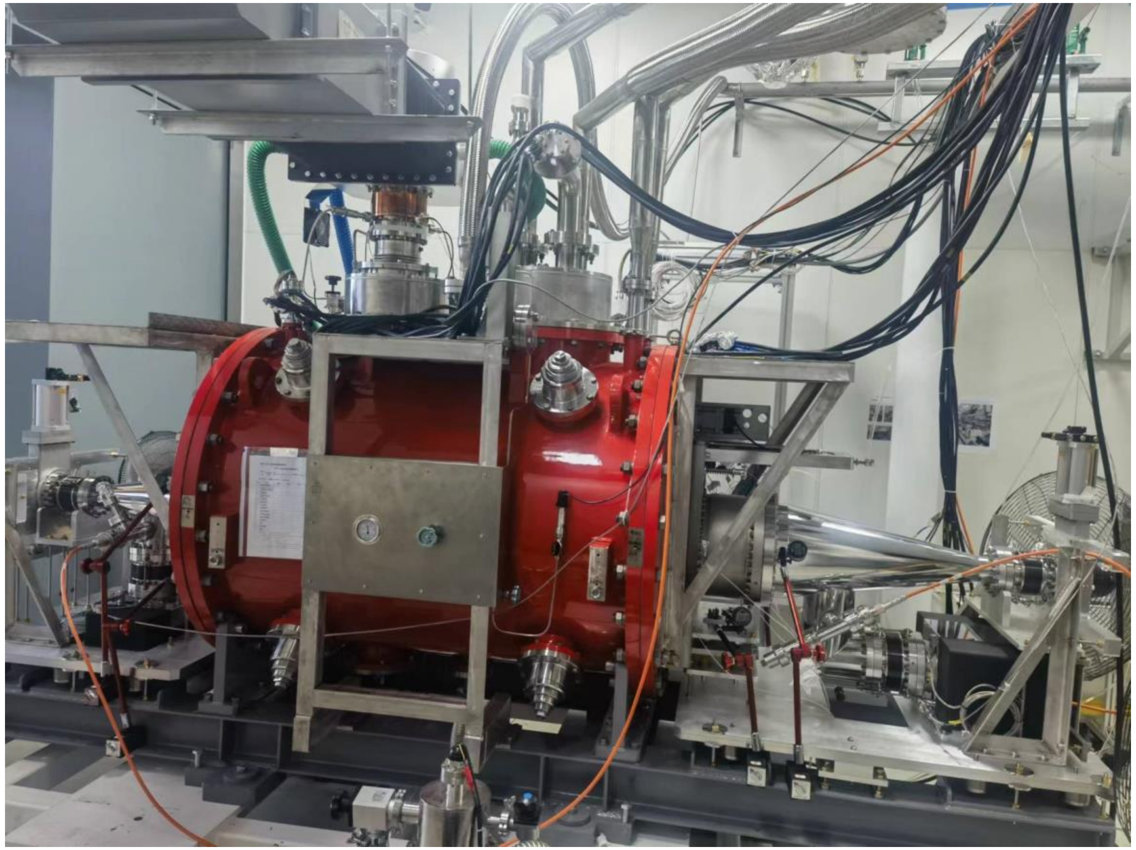


IHEP HEPS 166 MHz Cavity and Cryomodule prototype





HEPS 166.6MHz and 499.8MHz cryomodule



- Two 166.6MHz have past horizontal test, another three will be test in the next 3 or 4 month.
- Two 499.8MHz cryomodule have past test, one of which had been installed in the tunnel for HEPS first round commissioning.

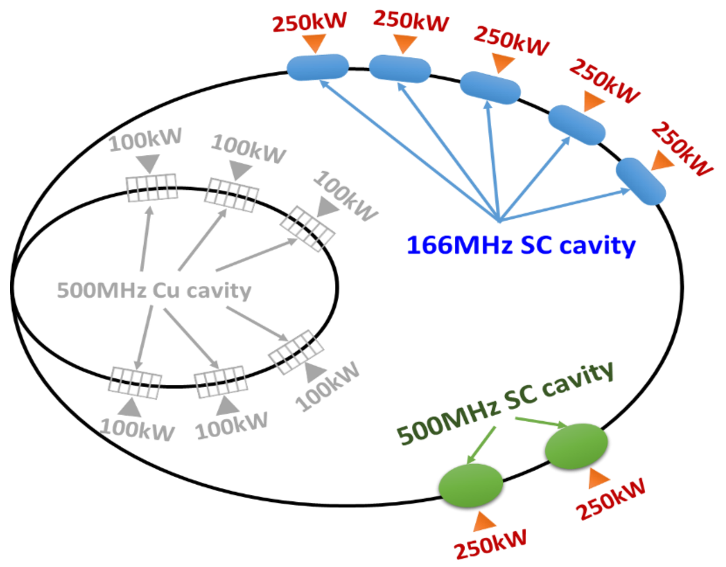
HEPS cryogenic system

Helium cryogenic system

- cool down five166.6MHz and two 499.8MHz superconducting cavities;
- Cooling capacity ~2000 W@4.5K;
- Auxiliary system, impure helium gas recovery and purify system.

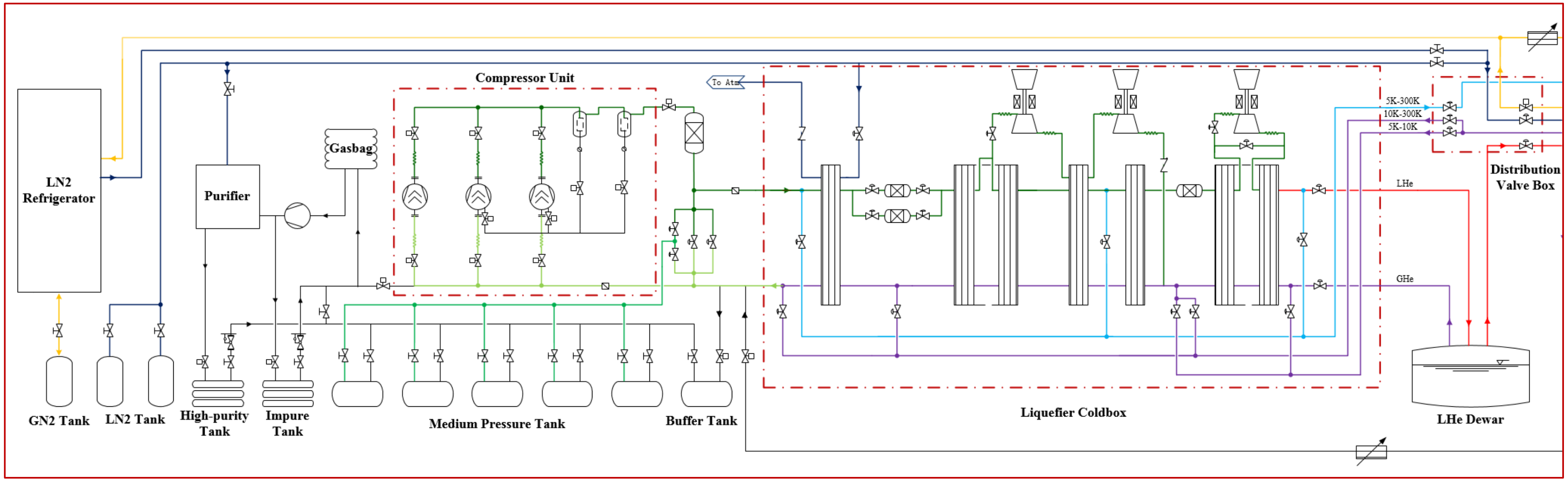
LN2 cryogenic system

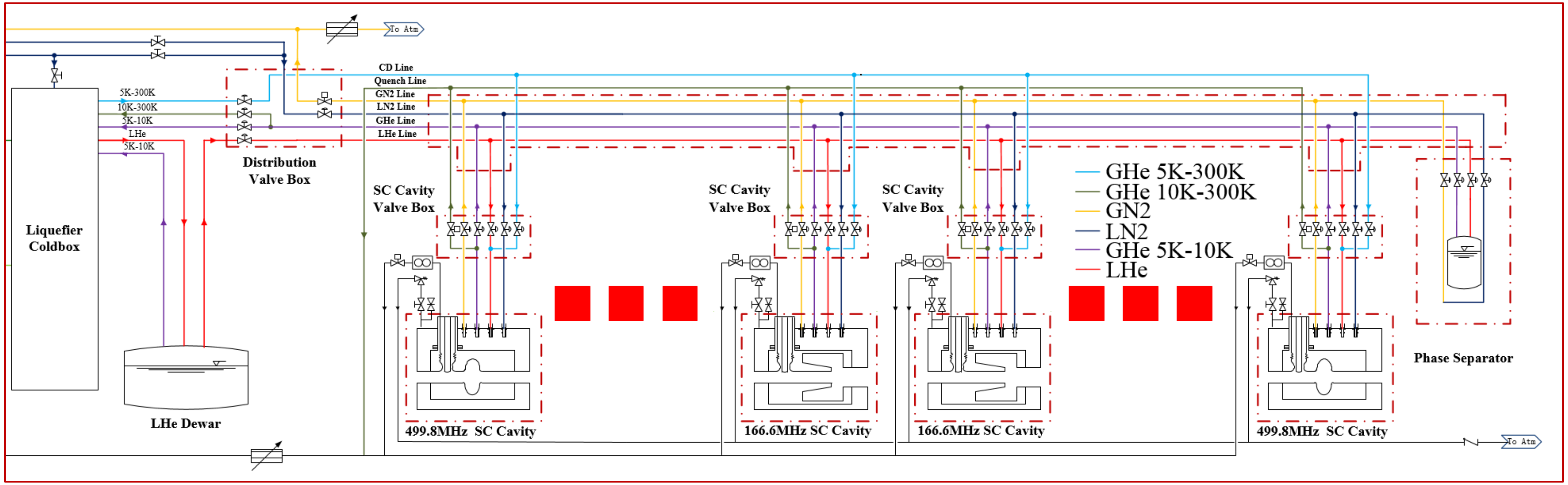
- cool down CPMU and Cryostal-Monochromator, cryogenic devices of Beam line station …;
- Precooling of the refrigerator;
- Shields of the superconducting cavities' cryostat
- Cooling capacity ~46kW@80K.



1. Engineering Materials	60-170keV
2. Hard X-ray Multi-analytical Nanoprobe (HXMAN)	< 10nm; in situ nanoprobe; 200m long
3. Structural Dynamics Beamline (SDB)	Single shot for irreversible; 200m long
4. Hard X-ray Coherent Scattering	CDI, XPCS
5. Hard X-ray High Energy Resolution Spectroscopy	NRS, Raman and RIXS
6. High Pressure	Diffraction; 150nm, ultrahigh pressure
7. Hard X-Ray Imaging	Up to 300keV, 300mm beam size, 350m long
8. X-ray Absorption Spectroscopy	Sub-micron, quick XAFS
9. Low-Dimension Structure Probe (LODISP)	Surface and interface
10. Biological Macromolecule Micro-focus	1μm, serial crystallography
11. Pink SAXS	pink, least optics
12. High Res. Nanoscale Electronic Structure Spectroscopy	ARPES, 200-2000eV
13. Tender X-ray	Spectroscopy, BM beamline
14. Transmission X-ray Microscope	Nano imaging and spectroscopy
15. Test beamline	X-ray optics test

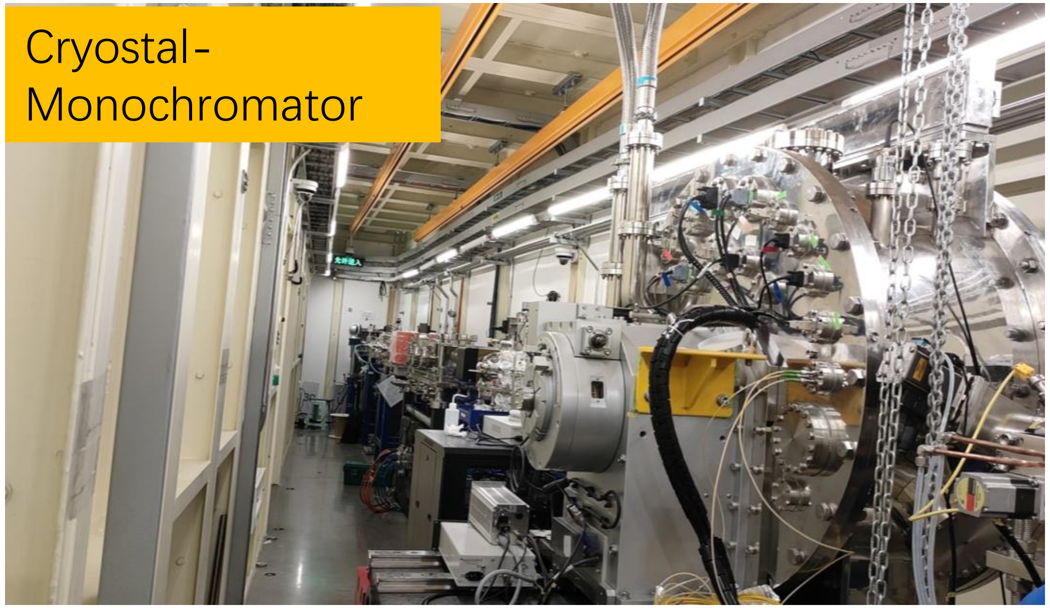
HEPS helium cryogenic system





HEPS key equipment with LN2 cool down


LN2 phase separator


Cryostal-Monochromator


LN2 sub cooling cold box


CPMU

HEPS cryogenic system site construction

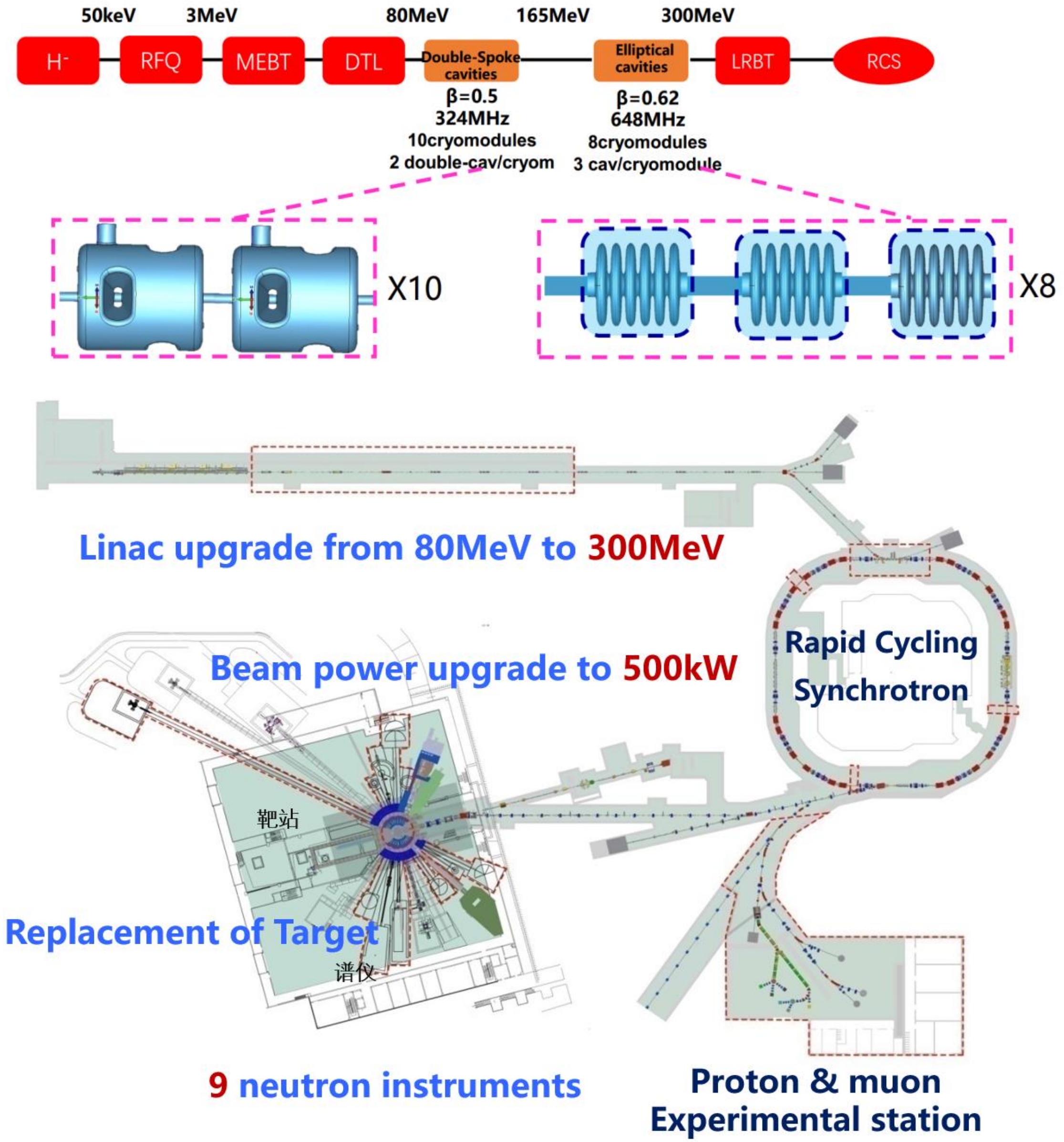


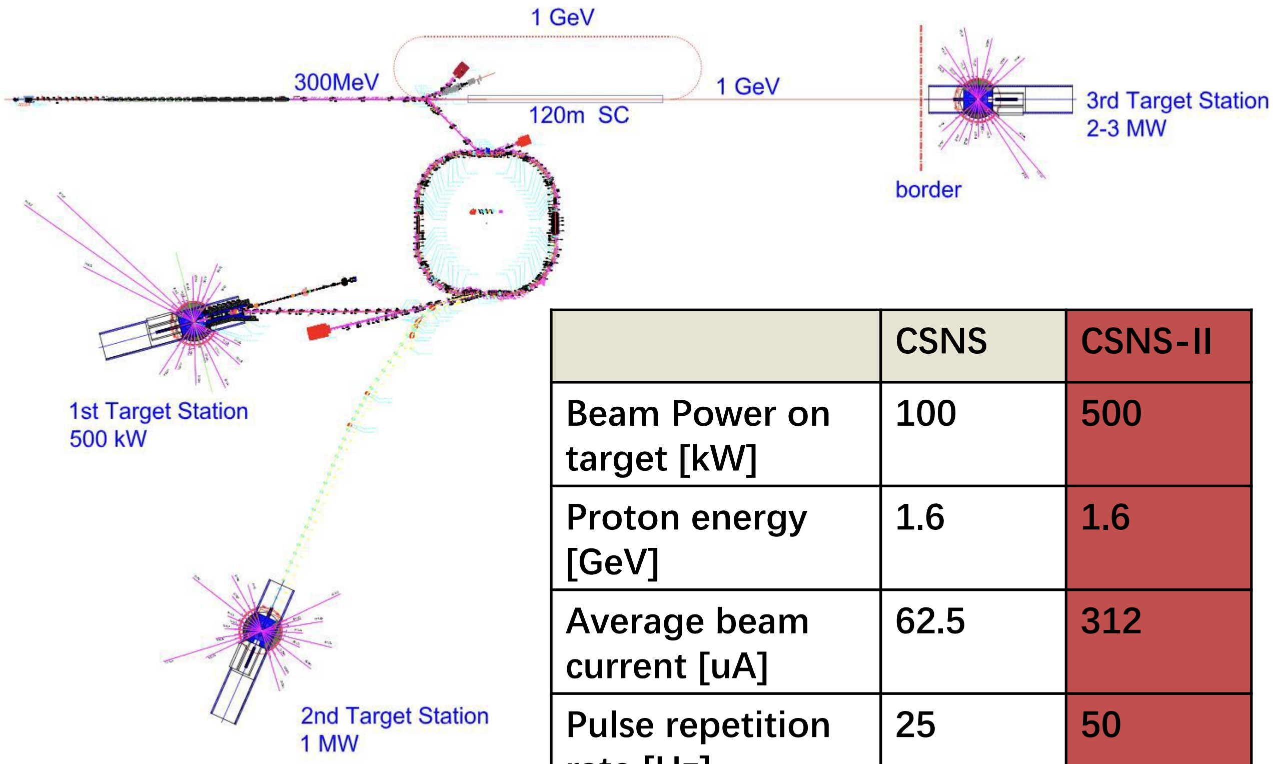

HEPS cryogenic system commissioning and operation

- **HEPS project have finished the first round beam commissioning and beam light experiment, the cryogenic system stable operation support the whole process.**
- **The SRF cryomodules will be installed in the tunnel in June 2025, and then is the beam and light commissioning, the goal of this year is to realize the technical acceptance.**

IHEP CSNS

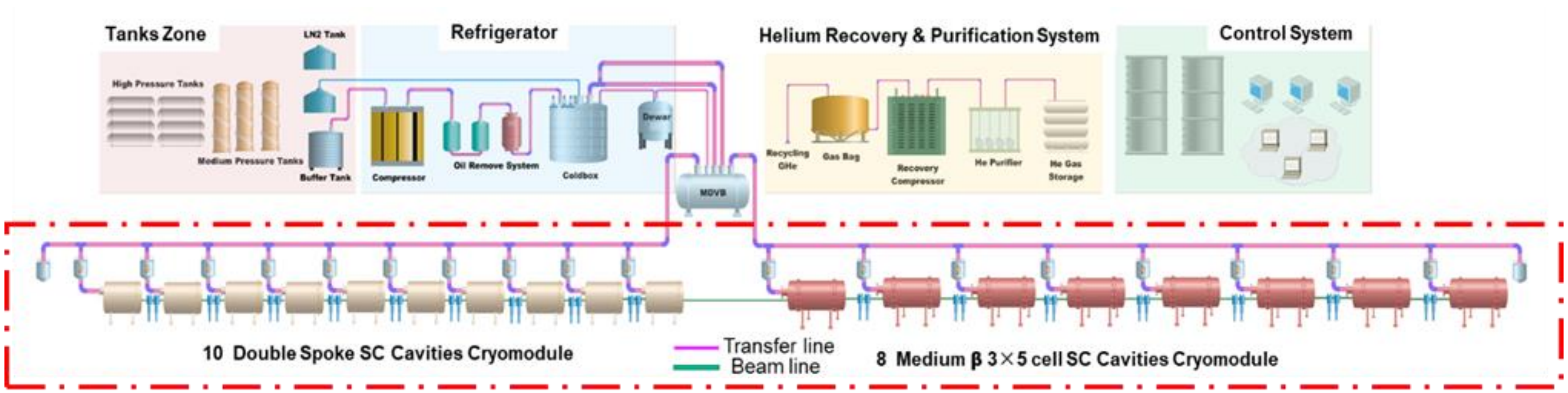
CSNS-II and Future Plan January 2024—October 2029





	CSNS	CSNS-II
Beam Power on target [kW]	100	500
Proton energy [GeV]	1.6	1.6
Average beam current [uA]	62.5	312
Pulse repetition rate [Hz]	25	50
Linac energy [MeV]	80	300
Linac type	RT	RT+SC
Linac RF frequency [MHz]	324	324/648
Spectrometers	3	11+8

CSNS-II SRF System

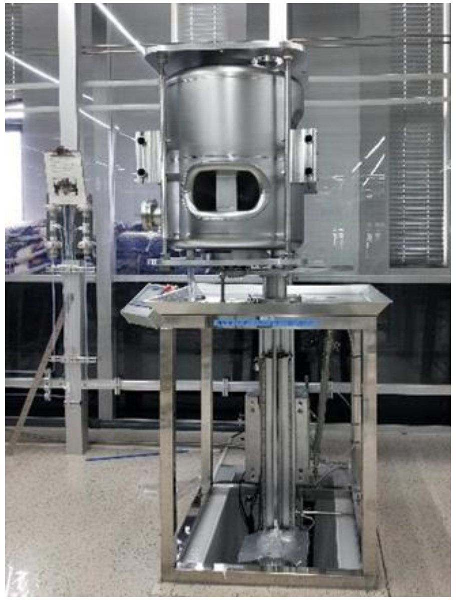


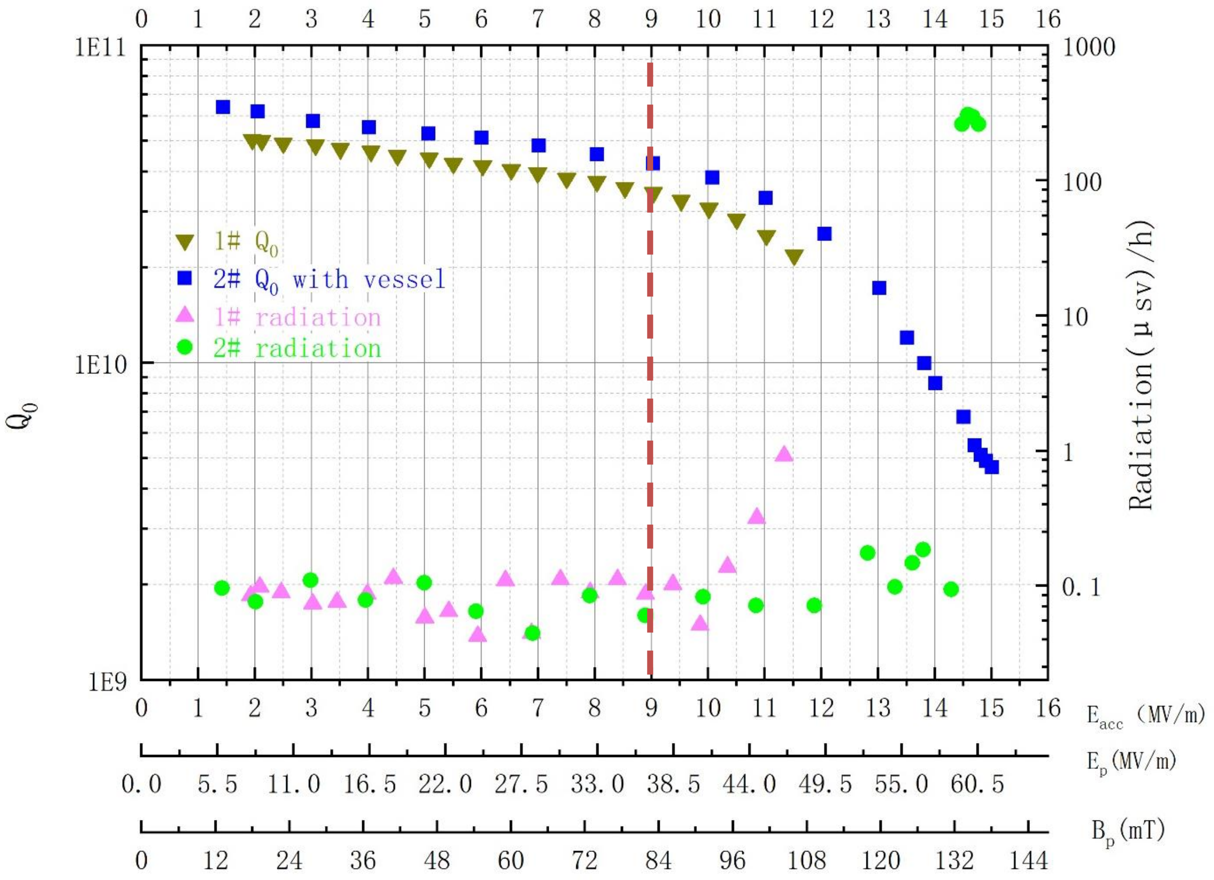
- **CSNS-II upgrade (2023-2028)**
  - Linac energy: 80 MeV → 300 MeV
  - Linac beam current: 15 mA → 40 mA
  - Linac beam pulse length: 400 μs → 600 μs
- **20 324 MHz β=0.5 double-spoke cavities**
  - Prototype cavities meet design spec
  - Prototype cryomodule under assembly at PAPS
- **24 648 MHz β=0.62 6-cell cavities**
  - Prototype cavity in fabrication, module in design

Parameter	Value
f (MHz)	324
TTF	0.79
β_0	0.5
Eacc (MV/m)	7.3 (9)
Ep/Eacc	3.44
Bp/Eacc mT/(MV/m)	8.86
R/Q (Ω)	401.8
G (Ω)	118.6

Parameter	Value
f (MHz)	648
TTF@βg	0.7
βg	0.62
Eacc (MV/m)	14
Ep/Eacc	2.53
Bp/Eacc mT/(MV/m)	5.45
R/Q (Ω)	309
G (Ω)	177
Beam tube diameter (mm)	105/120
Cell-cell coupling (%)	1.35

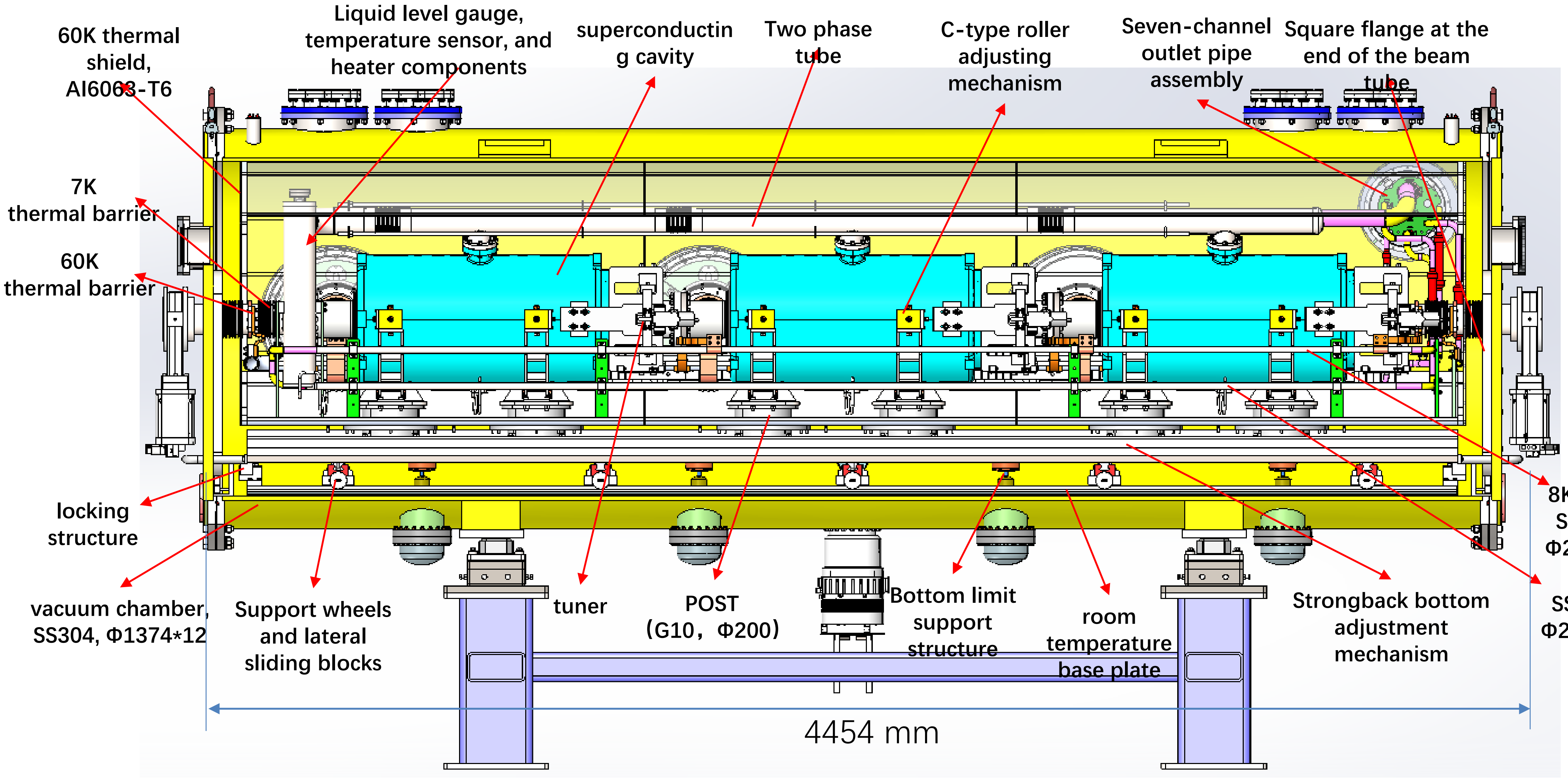
CSNS-II Double-Spoke Cavities



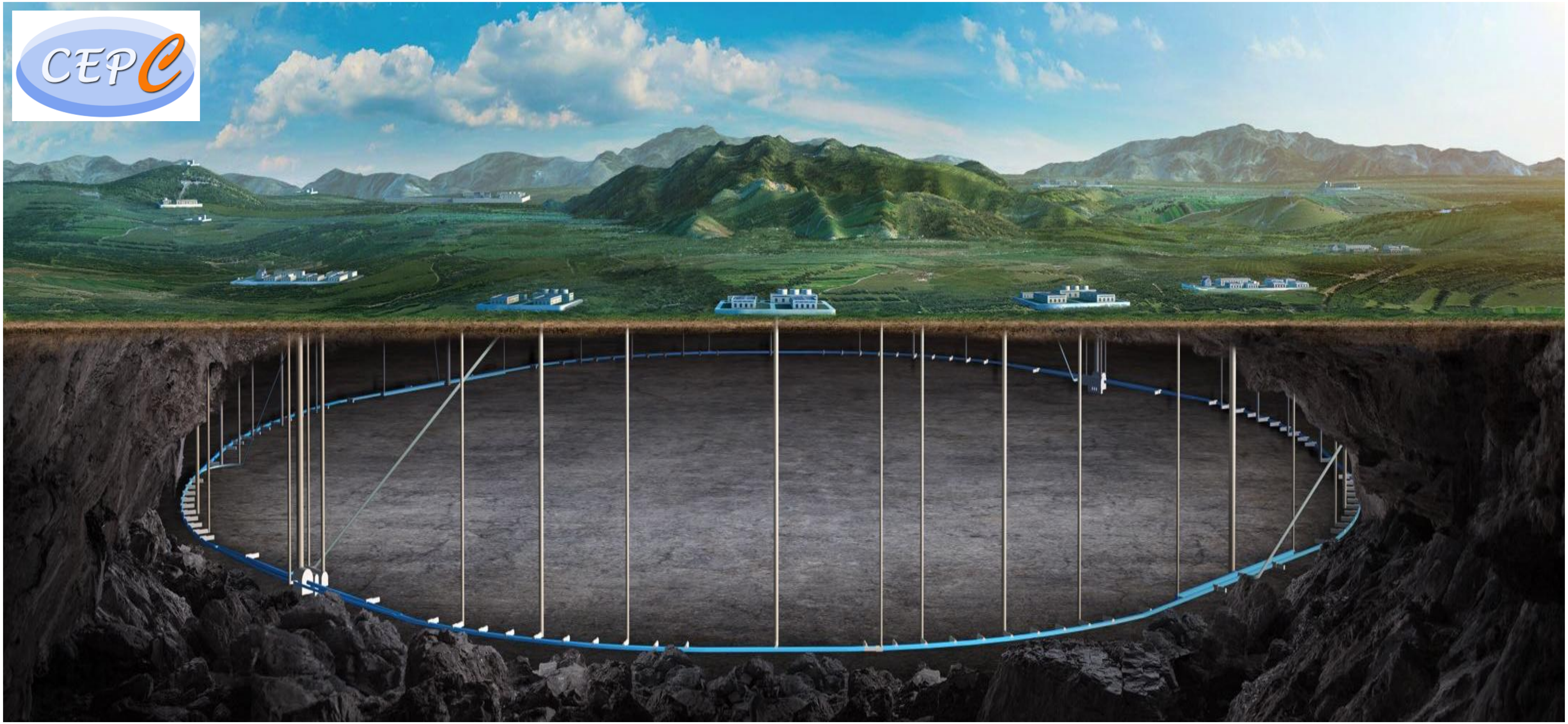


Prototype of 324MHz double spoke cavity cryomodule

648MHz elliptical cryomodule

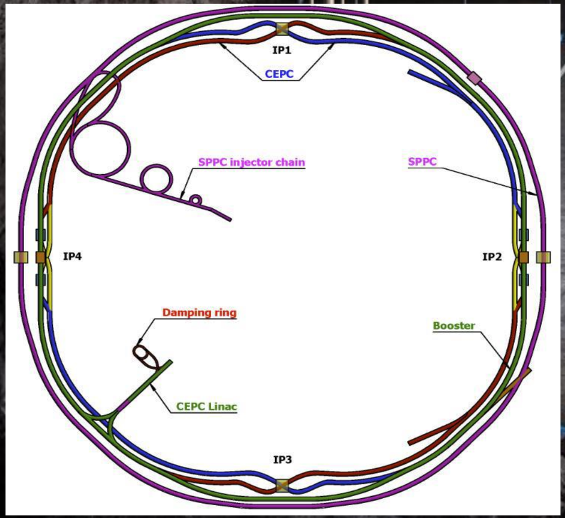


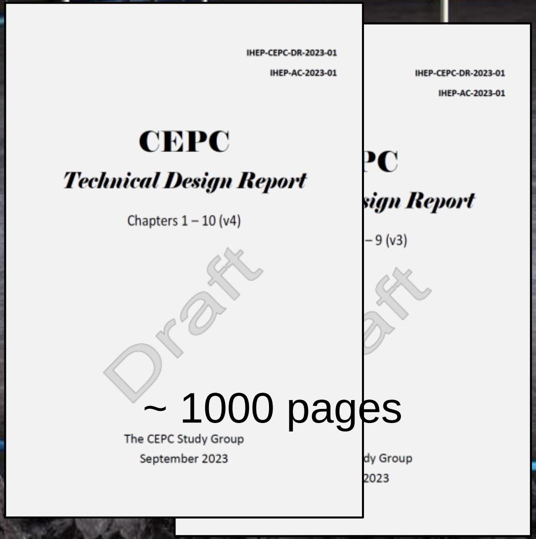
CEPC



CEPC

- 100 km circular collider, Higgs (Z / W / ttbar) factory, in China. Run at $\sqrt{s}$ ~ 90, 160, 240, 360 GeV. Possible *pp* collider (SppC) of $\sqrt{s}$ ~ 50 - 100 TeV in the far future.
- CEPC CDR published in 2018, TDR will publish in late 2023. Will propose to the government to begin construction around 2028 during the 15th 5-year-plan period.
- CEPC SRF system has unprecedented challenges in high RF voltage (20 GV) , high current (1.4 A), high power (100 MW RF power, Z-pole 1 MW per cavity) , high HOM power and beam-cavity interaction issues, with requirement of mode switching. State-of-the-art technology in high gradient, high Q and high power.



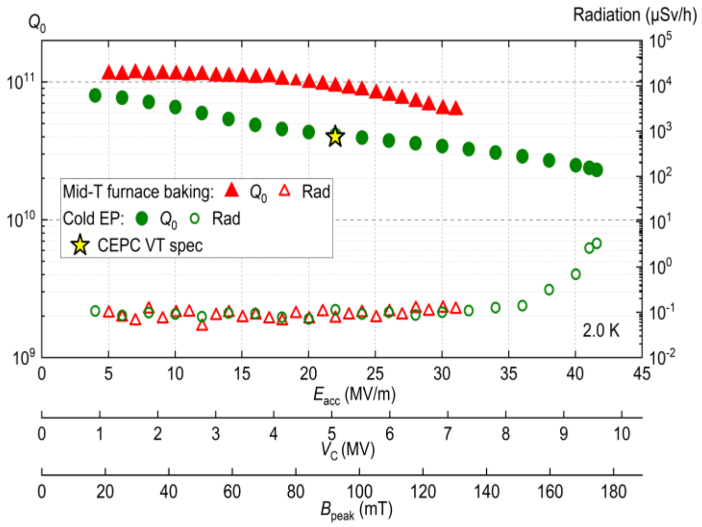

IHEP-CEPC-DR-2023-01
IHEP-AC-2023-01
CEPC
Technical Design Report
Chapters 1 – 10 (v4)
Draft
The CEPC Study Group
September 2023

~ 1000 pages

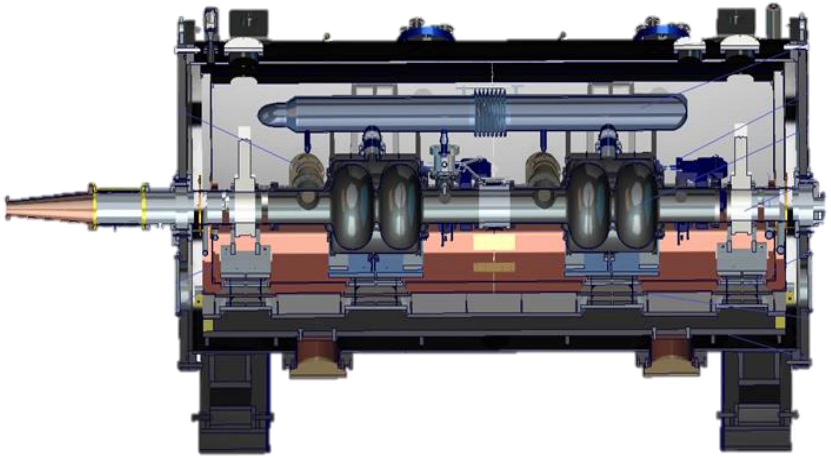

CEPC TDR Review, June 12-16 2023

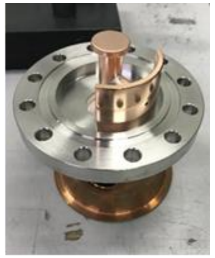
CEPC 650 MHz SRF System R&D

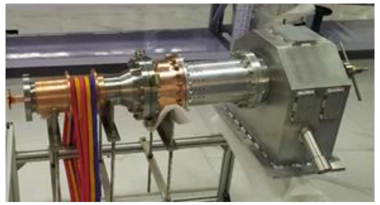
650 MHz test cryomodule with 2x2-cell cavities. Beam test soon.

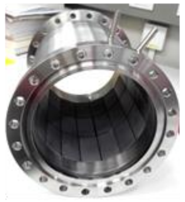


High G High Q 650 MHz 1-cell Cavity
EP treated: 2.3E10@41.6 MV/m@2 K
Mid-T treated: 6.3E10@31 MV/m@2 K

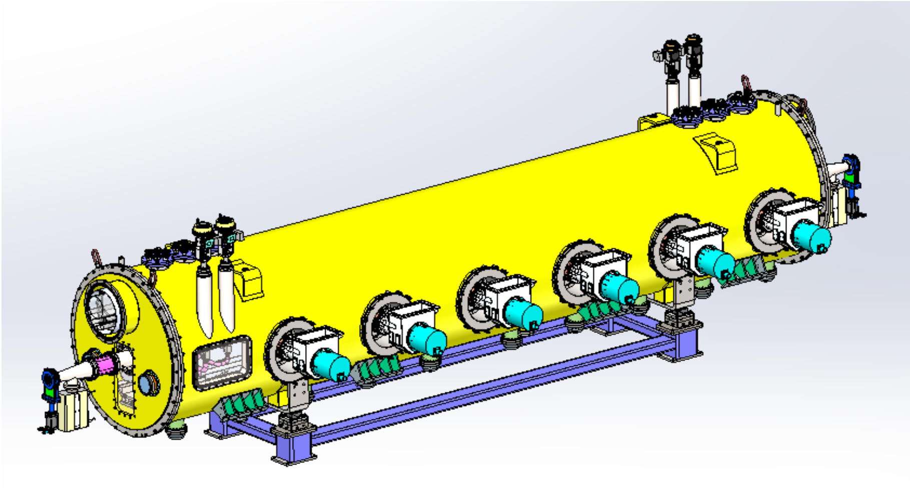
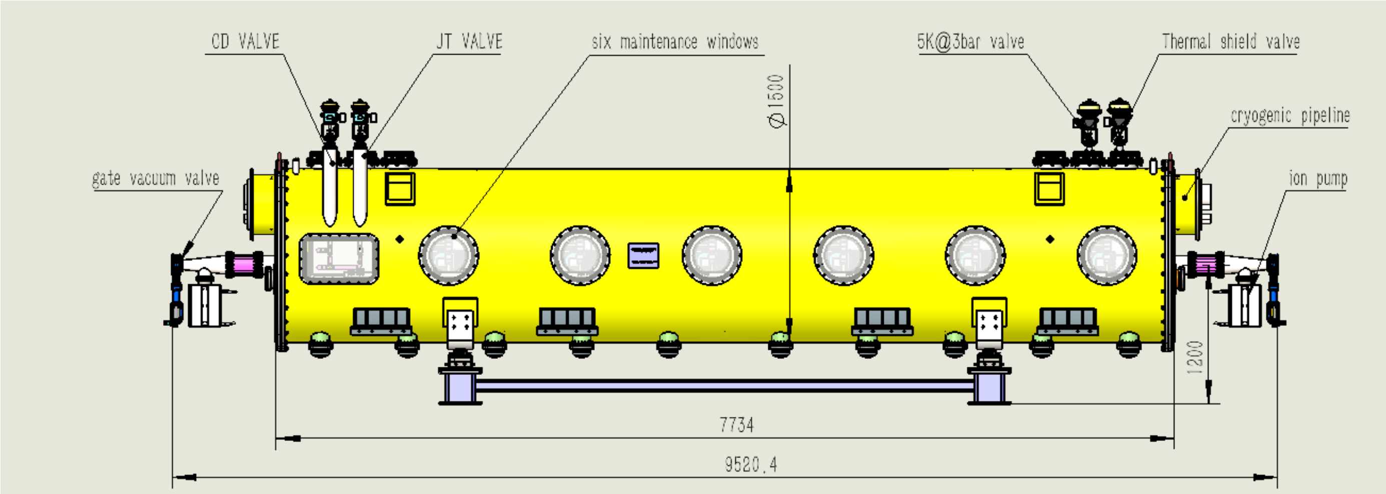


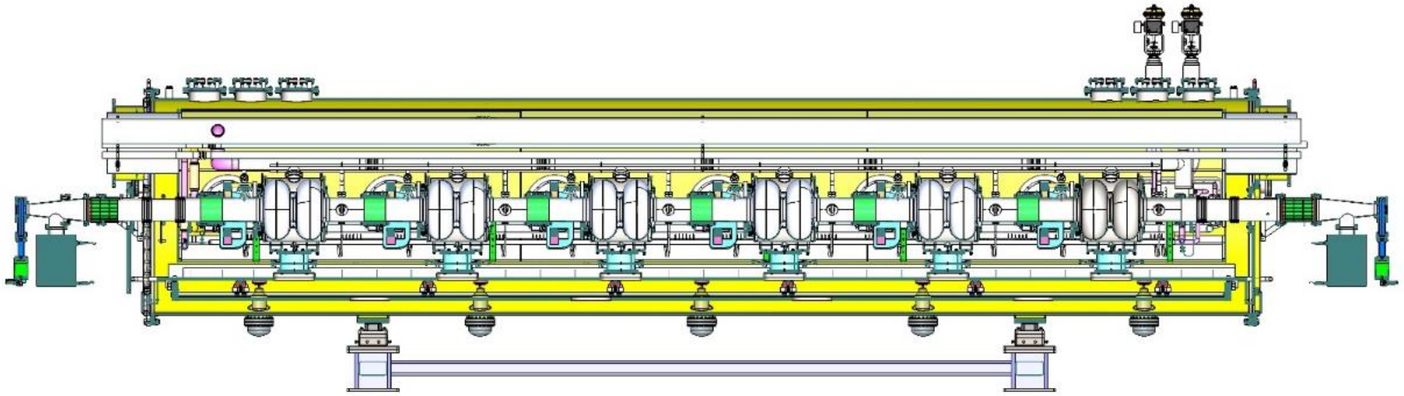
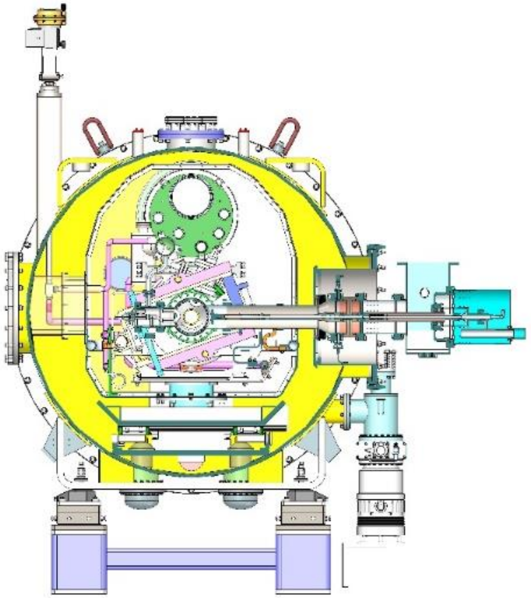
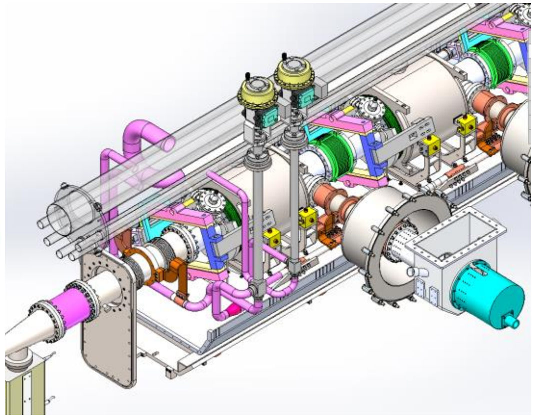






Full size 650 MHz Module Design

IHEP 1.3 GHz SRF R&D

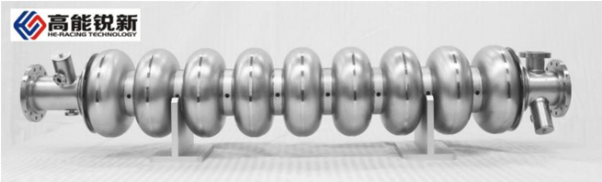
2003-2015	2016-2020	2021-2025	2026-2035
Early research Technology R&D	Technology transfer Performance breakthrough	Cavity mass production Cryomodule prototyping	Cavity and cryomodule mass production




1-cell and 9-cell cavities

ILC test cryomodule

Important collaboration with PKU, KEK, INFN-LASA, FNAL, JLAB, DESY …



HERT 11 TESLA 9-cell cavities

EP 36 MV/m (reach ILC spec)

Mid-T 5E10@21 MV/m (world record)

4 BCP + 4 mid-T high Q cavities delivered to SHINE

SHINE

88 9-cell cavities by HERT

DALS 1.3 GHz high Q cryomodule

Engage in these projects:

SHINE (600 CAV, 75 CM)

S^3FEL (208 CAV, 26 CM)

Other CW FELs

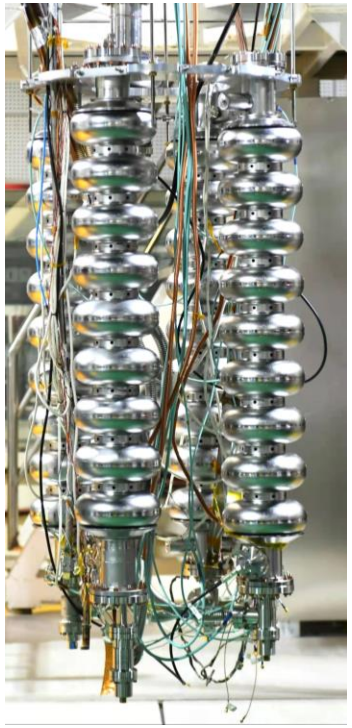
CEPC booster (352 cavities)

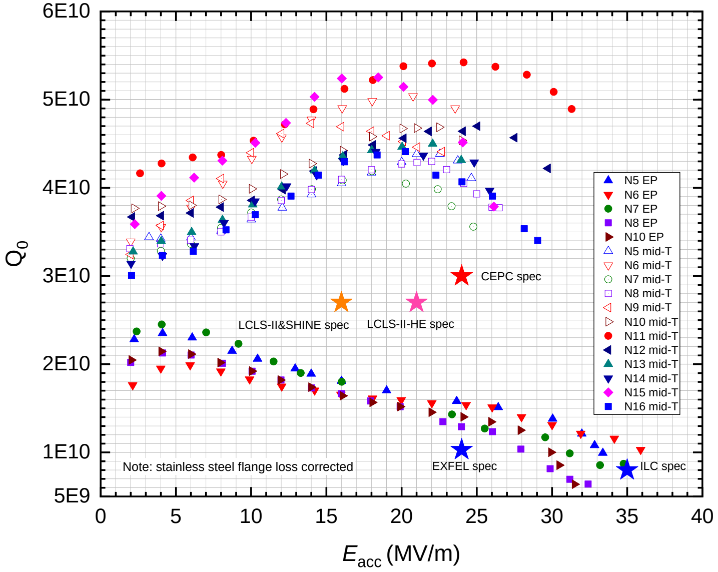
ILC (8000+8000 cavities)

…

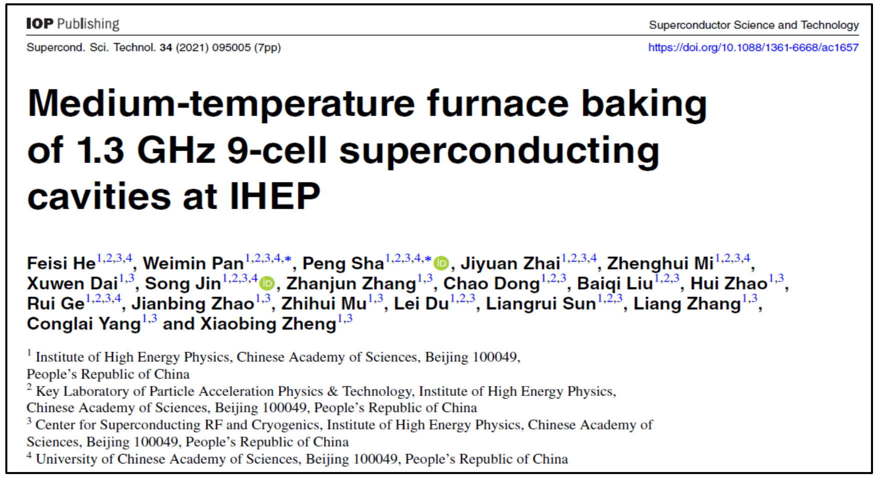
High Q high gradient and new material R&D

IHEP 1.3 GHz SRF R&D





High average Q_0 of 4.5E10 at 16 ~ 21 MV/m.
Mid-T bake recipe has distinct advantages over nitrogen-doping


IOP Publishing — Superconductor Science and Technology

Supercond. Sci. Technol. 34 (2021) 095005 (7pp) — https://doi.org/10.1088/1361-6668/ac1657

Medium-temperature furnace baking of 1.3 GHz 9-cell superconducting cavities at IHEP

Feisi He[1,2,3,4], Weimin Pan[1,2,3,4,*], Peng Sha[1,2,3,4,*], Jiyuan Zhai[1,2,3,4], Zhenghui Mi[1,2,3,4], Xuwen Dai[1,3], Song Jin[1,2,3,4], Zhanjun Zhang[1,3], Chao Dong[1,2,3], Baiqi Liu[1,2,3], Hui Zhao[1,3], Rui Ge[1,2,3,4], Jianbing Zhao[1,3], Zhihui Mu[1,3], Lei Du[1,2,3], Liangrui Sun[1,2,3], Liang Zhang[1,3], Conglai Yang[1,3] and Xiaobing Zheng[1,3]

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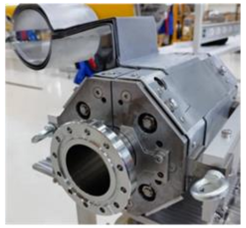
[3] Center for Superconducting RF and Cryogenics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[4] University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China

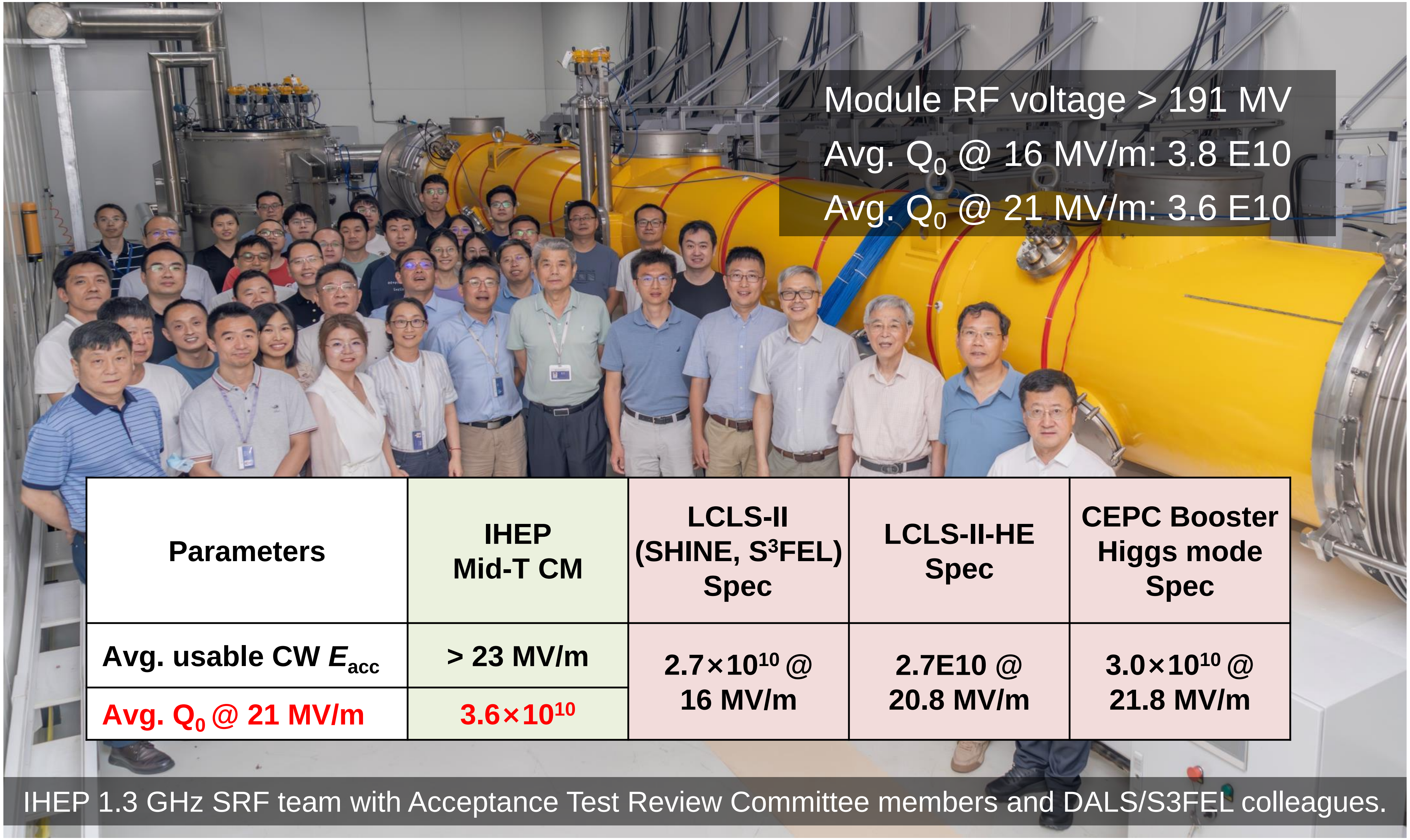








World's first Mid-T 1.3 GHz Cryomodule with Record High Q_0



Module RF voltage > 191 MV

Avg. Q_0 @ 16 MV/m: 3.8 E10

Avg. Q_0 @ 21 MV/m: 3.6 E10

Parameters	IHEP Mid-T CM	LCLS-II (SHINE, S3FEL) Spec	LCLS-II-HE Spec	CEPC Booster Higgs mode Spec
Avg. usable CW E_{acc}	**> 23 MV/m**	**2.7×10^{10} @ 16 MV/m**	**2.7E10 @ 20.8 MV/m**	**3.0×10^{10} @ 21.8 MV/m**
Avg. Q_0 @ 21 MV/m	**3.6×10^{10}**			

IHEP 1.3 GHz SRF team with Acceptance Test Review Committee members and DALS/S3FEL colleagues.

CEPC Cryogenic System Brief Introduction

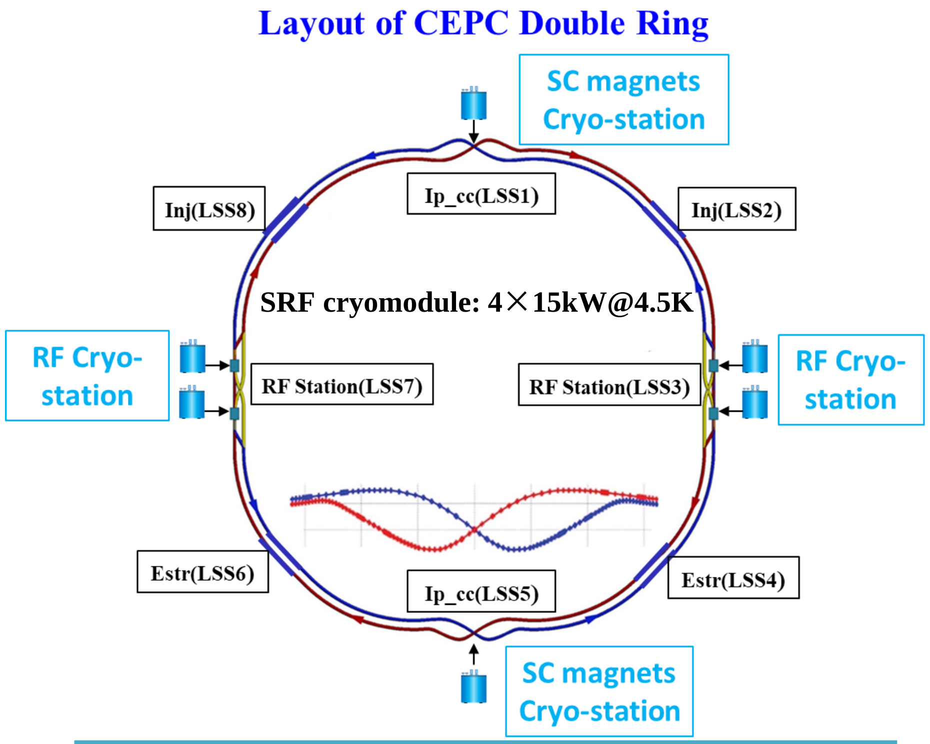
- CEPC is a positron and electron collider, and the beam is accelerated to 30 GeV by linear acceleration section, and then further accelerated to 120 GeV by RF cavities in the Booster and Collider ring.
- Cryogenic system is designed to provide a reliable and stable cooling environment (4.5K or 2K) for RF cavities and SC magnets.

Booster ring:

- 1.3 GHz 9-cell cavities, 96 cavities
- 12 cryomodules
- 3 cryomodules/each station
- Temperature: 2K

Collider ring:

- 650MHz 2-cell cavities, 240 cavities
- 32 cryomodules for Higgs 30MW, 56 for Higgs 50MW
- 8 or 14 cryomodules/each station
- Temperature: 2K



Overview of the CEPC cryogenic system

IR magnets:

- 4 IR magnets , 32 Sextuple magnets (room temperature)
- 4 cryostats
- Temperature: 4.5K/2K

Detectors:

- 2 detector magnets
- HeI/Thermosiphon cooling

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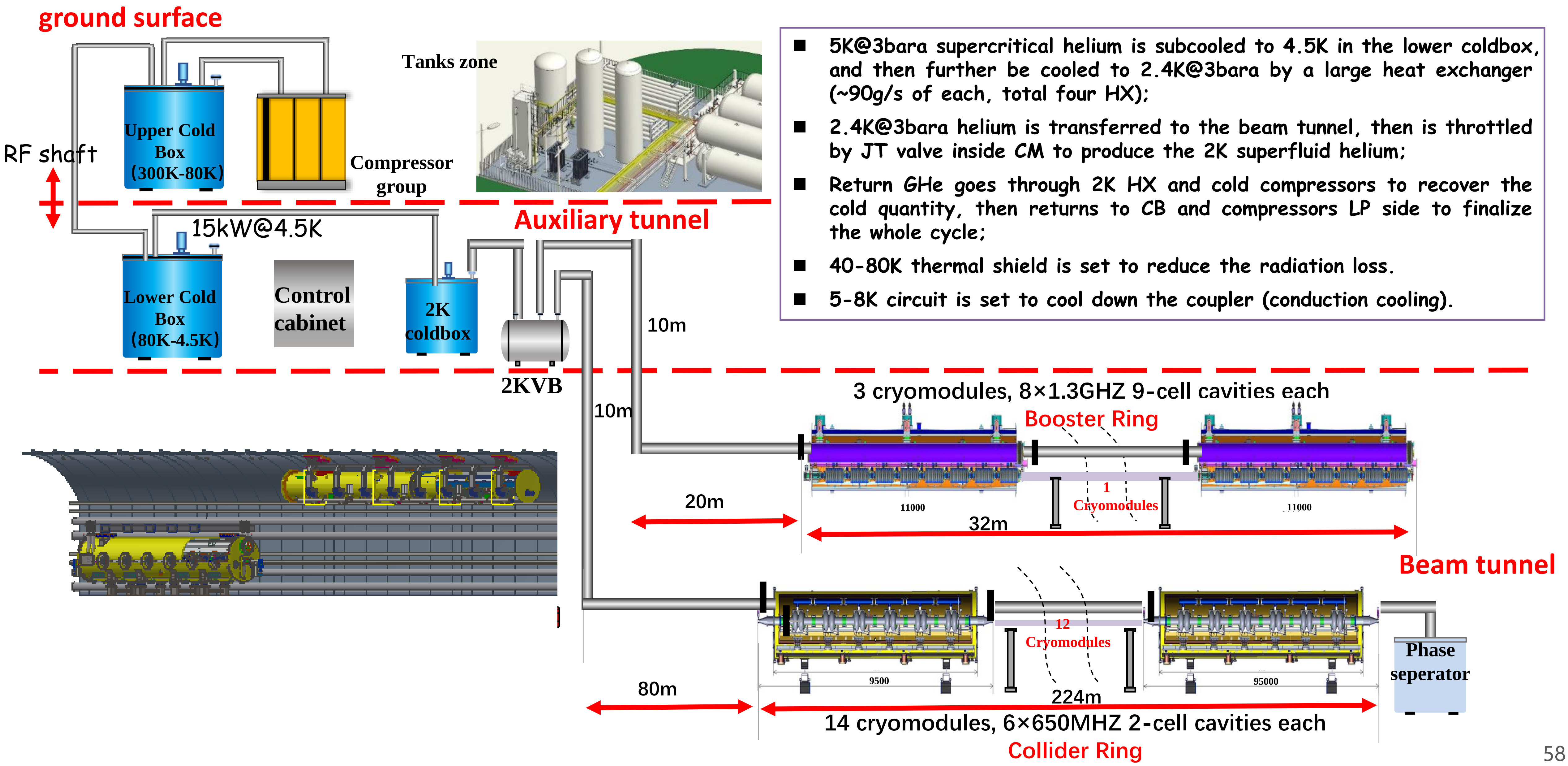
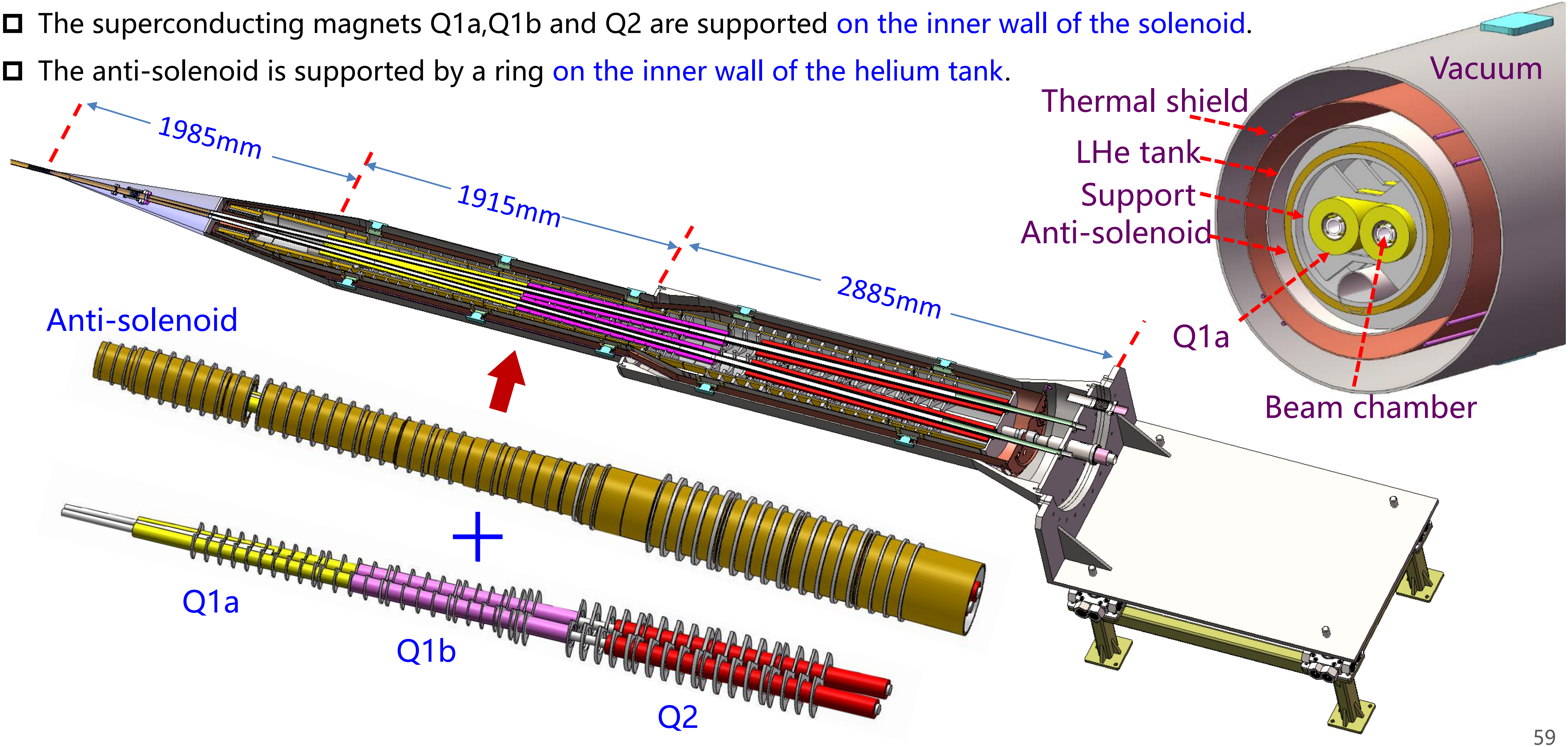
EDR—Flow chart of SRF Scheme



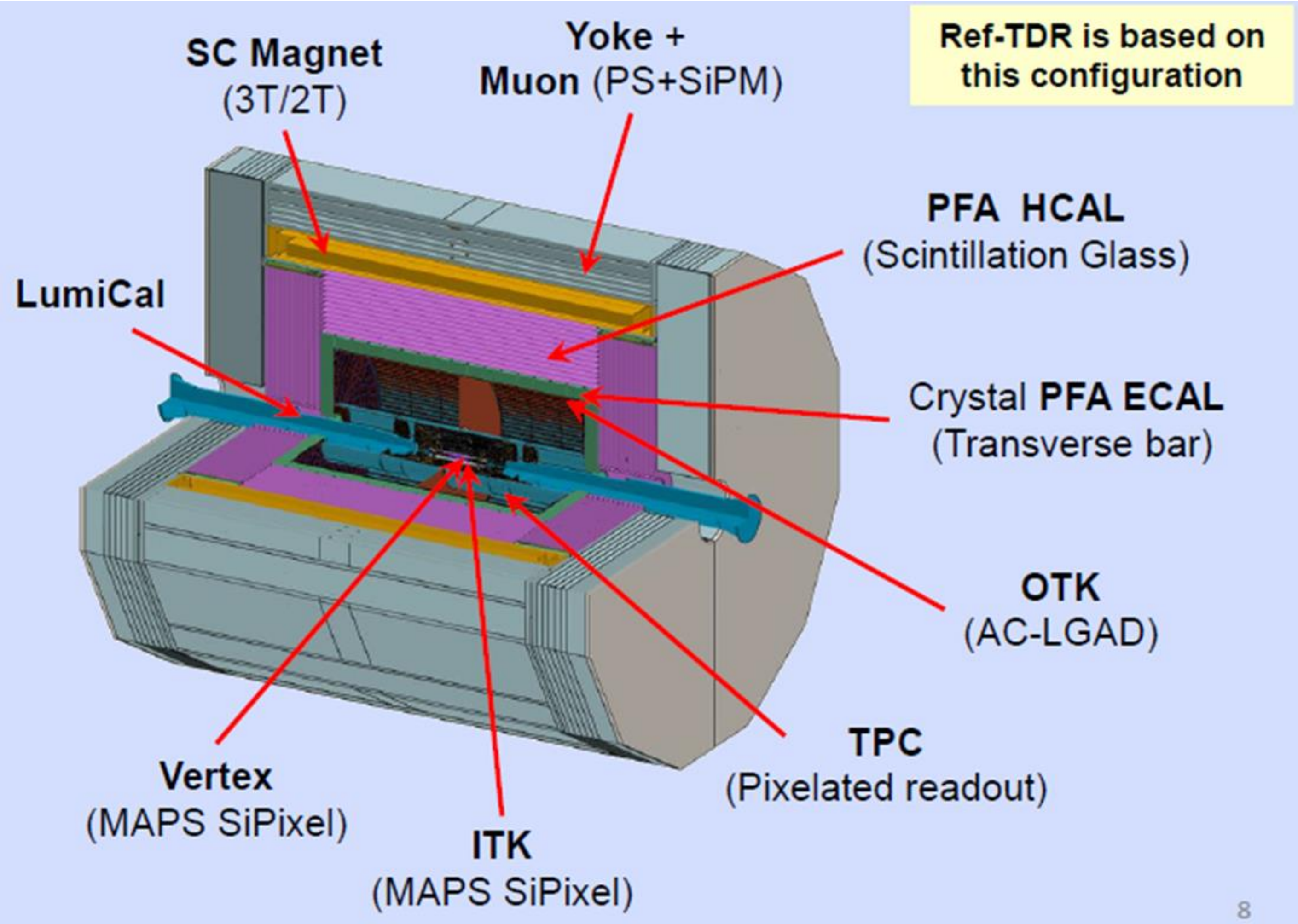
- 5K@3bara supercritical helium is subcooled to 4.5K in the lower coldbox, and then further be cooled to 2.4K@3bara by a large heat exchanger (~90g/s of each, total four HX);
- 2.4K@3bara helium is transferred to the beam tunnel, then is throttled by JT valve inside CM to produce the 2K superfluid helium;
- Return GHe goes through 2K HX and cold compressors to recover the cold quantity, then returns to CB and compressors LP side to finalize the whole cycle;
- 40-80K thermal shield is set to reduce the radiation loss.
- 5-8K circuit is set to cool down the coupler (conduction cooling).

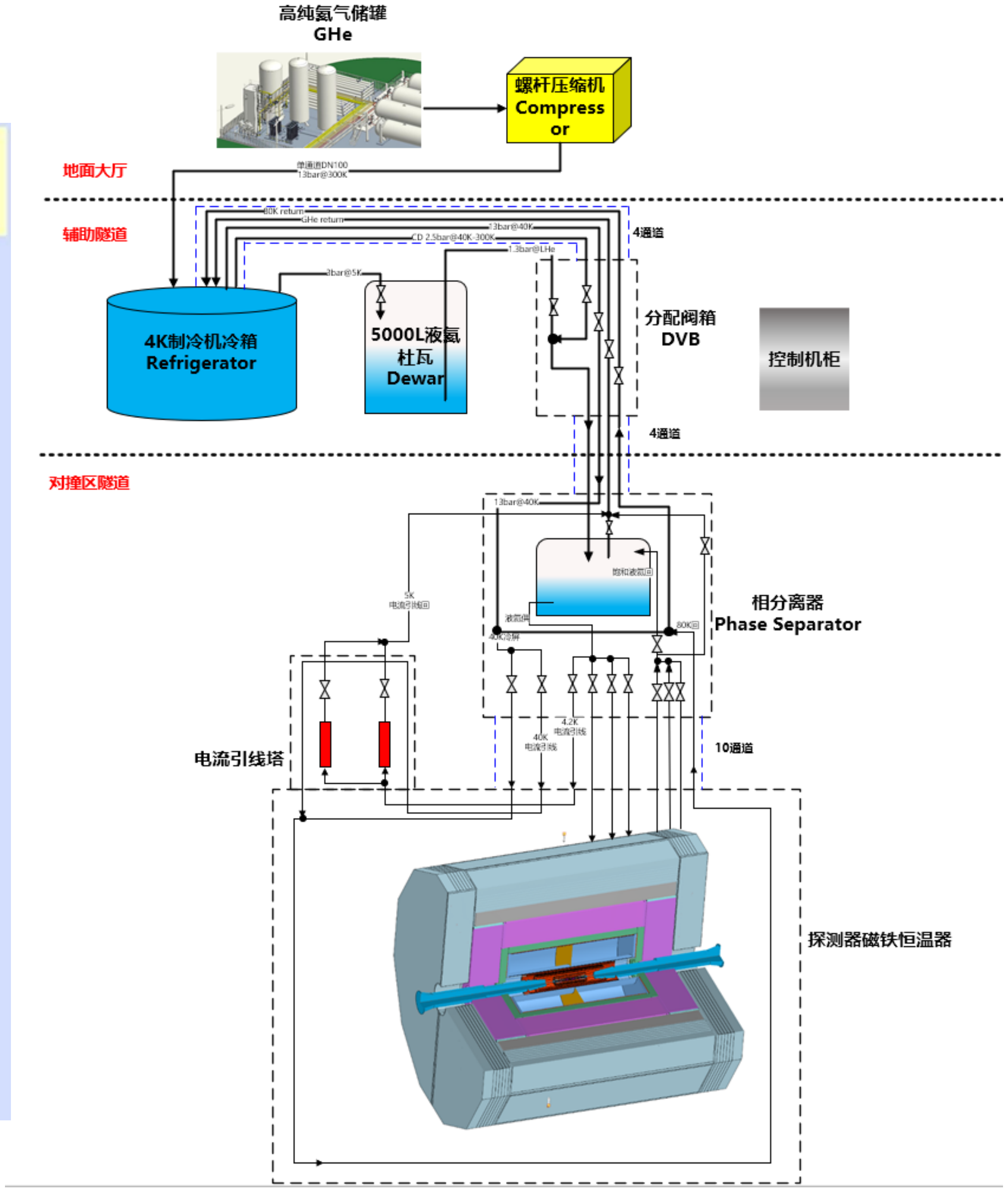
CEPC MDI SC magnet cryostat design

- The superconducting magnets Q1a,Q1b and Q2 are supported on the inner wall of the solenoid.
- The anti-solenoid is supported by a ring on the inner wall of the helium tank.



CEPC detector cryogenic system





Content

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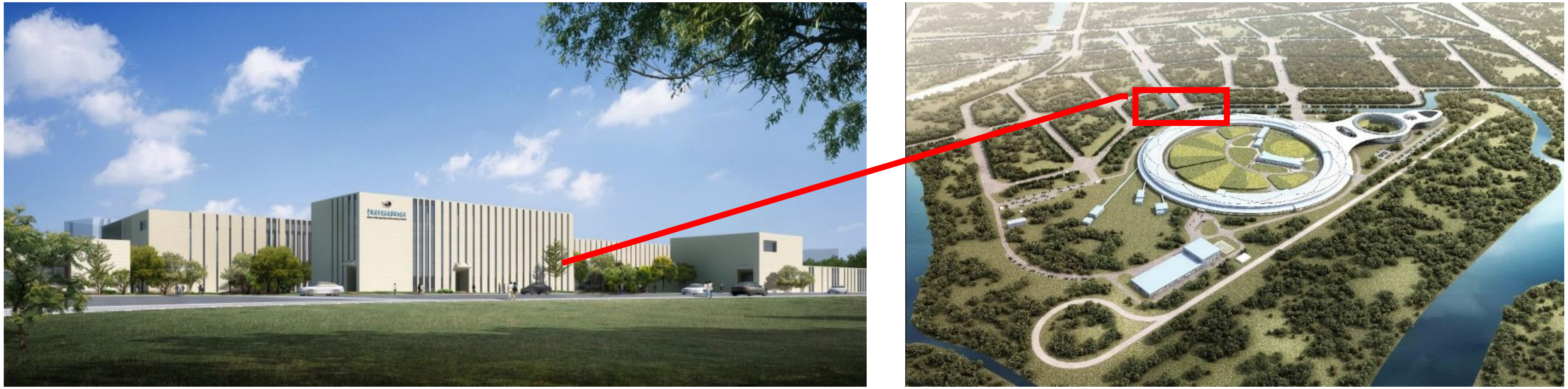
2. SRF accelerator projects
3. R&D and infrastructures at IHEP
4. Summary

Platform of Advanced Photon Source Technology R&D (PAPS)



- 先进光源技术研发与测试平台 Platform of Advanced Photon Source Technology R&D (PAPS)
  - 加速器分平台 Accelerator platform
    - 超导高频系统 RF system
    - 低温系统 Cryogenic system
    - 精密磁铁系统 Magnet technology
    - 束流测试系统 Beam test
  - X射线分平台 X-Ray platform
    - X射线光学系统 X-ray optics
    - X射线探测系统 X-ray detection
    - X射线应用系统 X-ray application

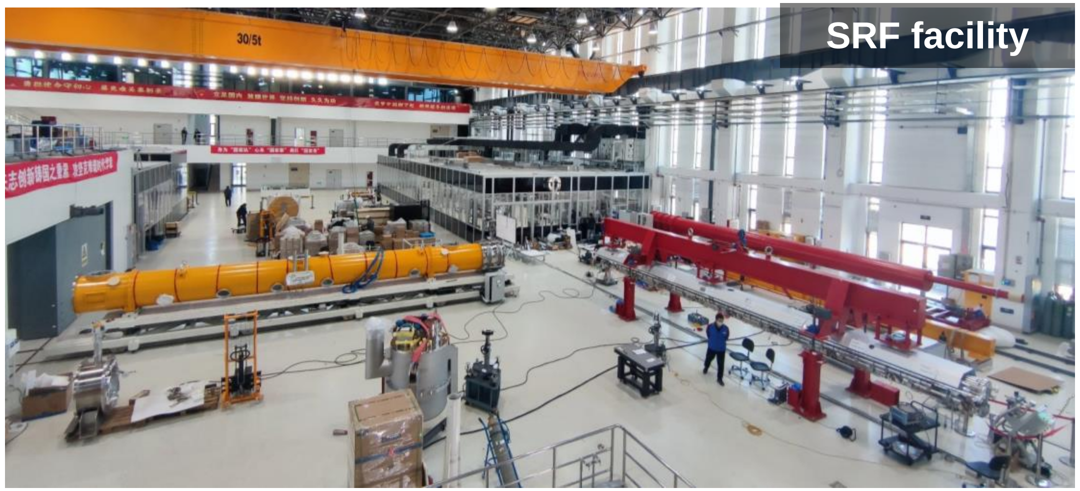
- “Platform of Advanced Photon Source Technology R&D”, The goal of the PAPS project is to provide a good foundation and condition for R&D, engineering testing and verification for the high energy phone source (HEPS) project to be completed on schedule and to achieve the expected design target.
- Budget: 590M CNY funded by Beijing Gov.
- Construction: 2017.5-2021.6

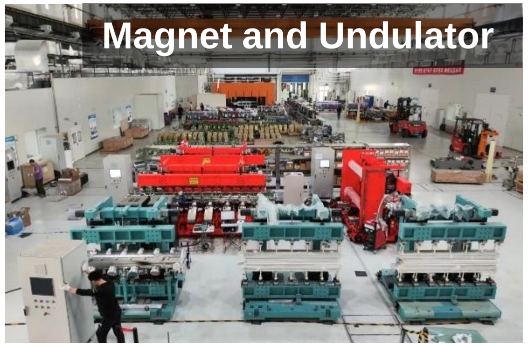
IHEP Huairou campus HEPS and PAPS project

PAPS SRF Infrastructure Testing Capability and Status

Facilities (capability per year)	Devices	Tests since 2021	Related Projects
Cavity vertical test stand (400 cavities per year)	**Cavities**: 166 MHz, 325 (324) MHz, 500 MHz, 650 (648) MHz, 1.3 GHz	~ 200	HEPS, BEPCII-U, CEPC, CSNS-II, SHINE, DALS, RAON …
Cryomodule assembly and horizontal test stand (20 modules per year)	**Cryomodules**: 166 MHz, 324 MHz, 500 MHz, 650 MHz, 1.3 GHz	~ 20	HEPS, DALS, BEPCII-U, CSNS-II, CEPC …
Coupler high power test stand (200 couplers per year)	**Couplers**: 166 MHz, 324 MHz, 500 MHz, 650 MHz, 1.3 GHz	~ 40	HEPS, SHINE, DALS, CSNS-II, CEPC …
Clean assembly and HPR (2 assembly lines and 2 HPRs)	**Cavities and cavity strings**: 166 MHz, 324 MHz, 500 MHz, 650 MHz, 1.3 GHz	~ 180	HEPS, CEPC, CSNS-II, SHINE, DALS, BEPCII-U …

IHEP PAPS SRF Infrastructure in Huairou, Beijing

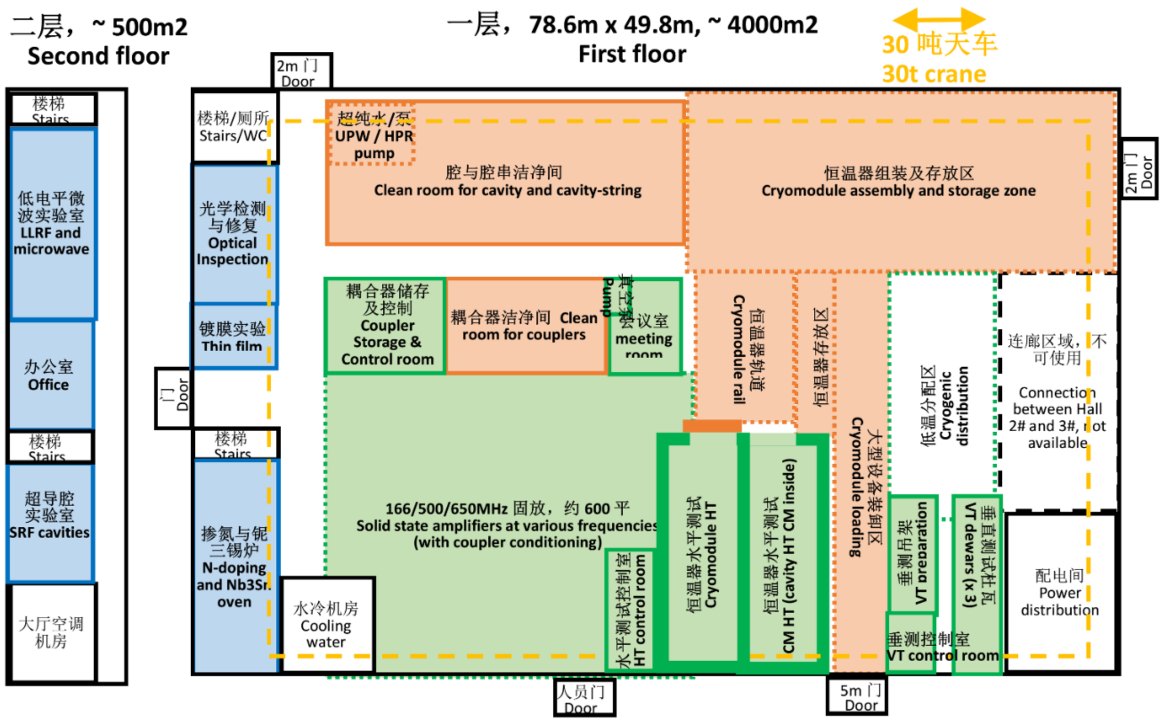


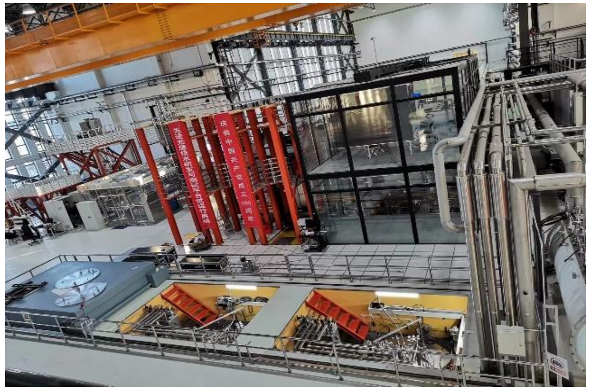


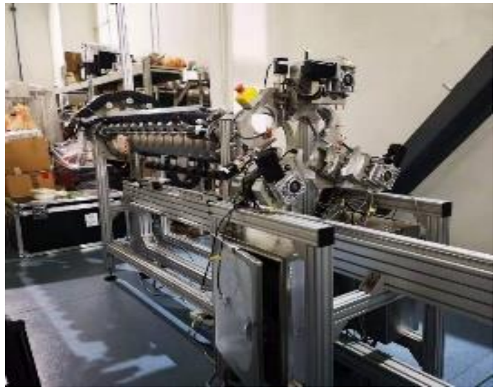
Accelerator key technology R&D and Testing platform:

- SRF cavity and module
- High precision magnet
- Vacuum assembly & coating
- High efficiency Klystron
- Mechanics and alignment
- Beam test facility

IHEP PAPS SRF Infrastructure Fully Operational



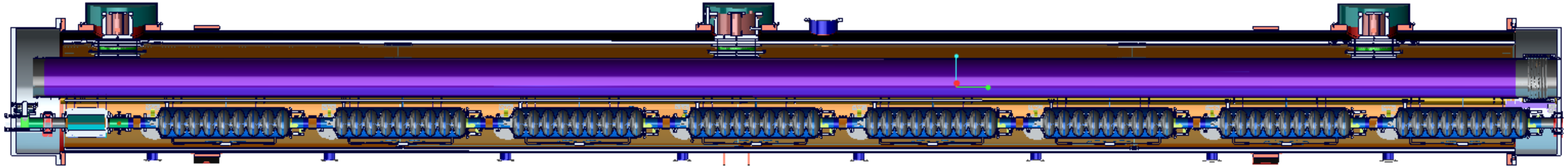


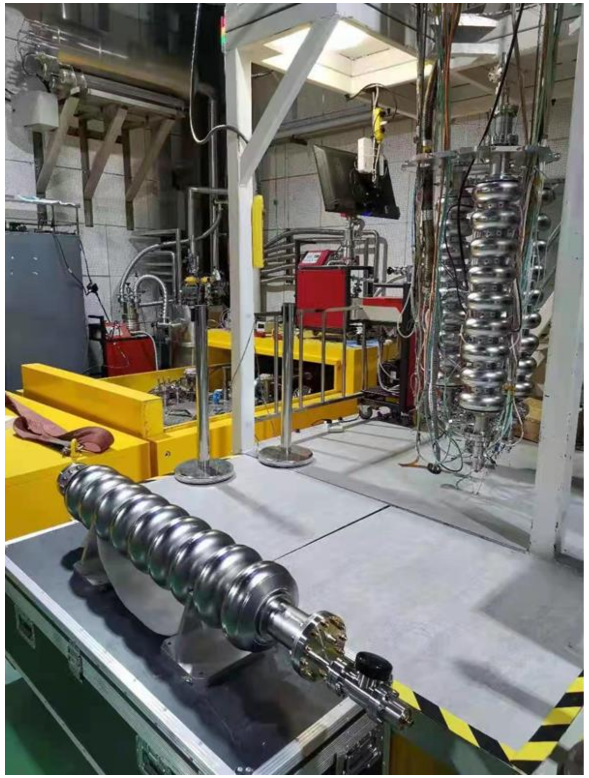


IHEP EP system in Ningxia

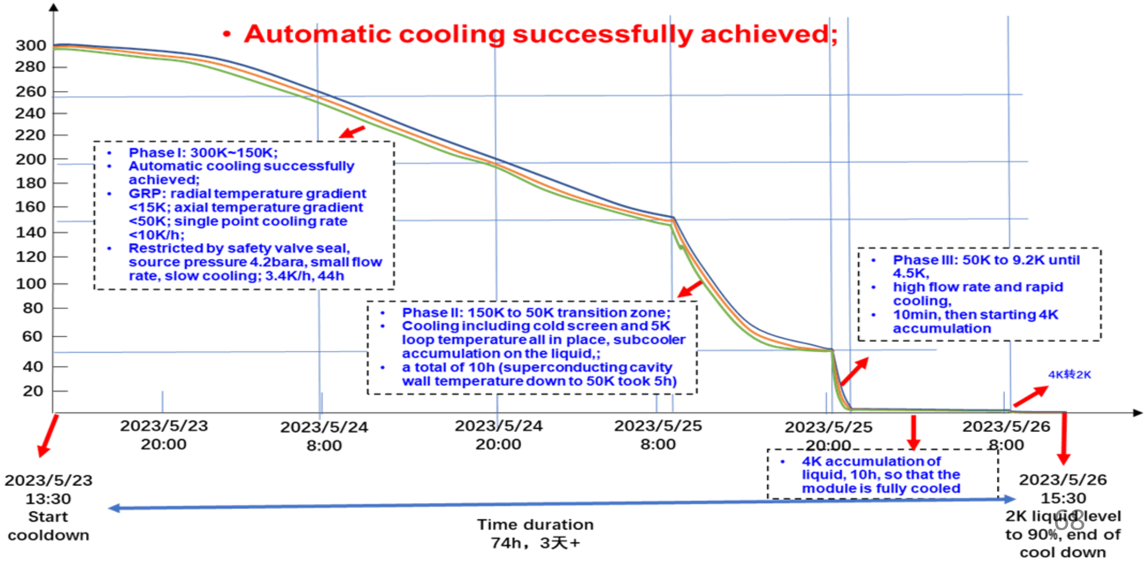
Important achievement based on PAPS

1.3GHz high Q cryomodule reached the highest level, which would contribute to the undergoing facilities such as SHINE S^3FEL and even future CEPC





1.3GHz cryomodule integrated and cryogenic test

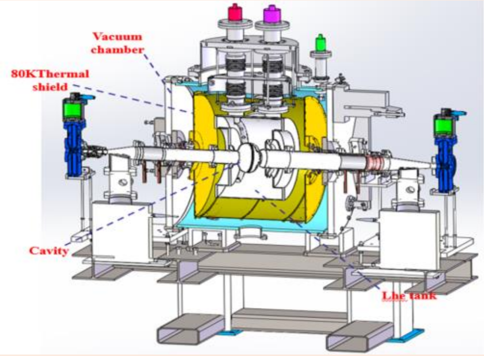


IHEP SRF Modules

166 MHz 1+4 CMs
(HEPS)

500 MHz 4+1 CMs
(BEPC-II & U, HEPS, HALF)

325 MHz 3+N CMs
(ADS, RAON 7/6xSSR)

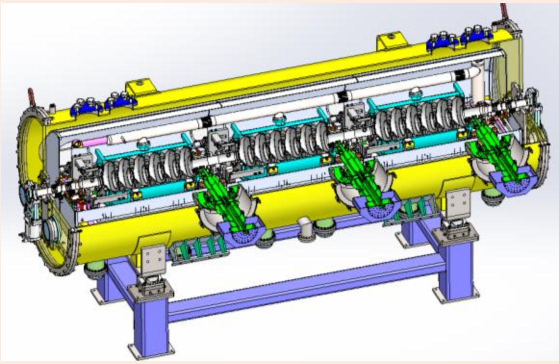


1.5 GHz +1 CM
(HALF, passive)

1.3 GHz 1+1 (N) CMs
(CEPC, FEL, ILC, ERL)

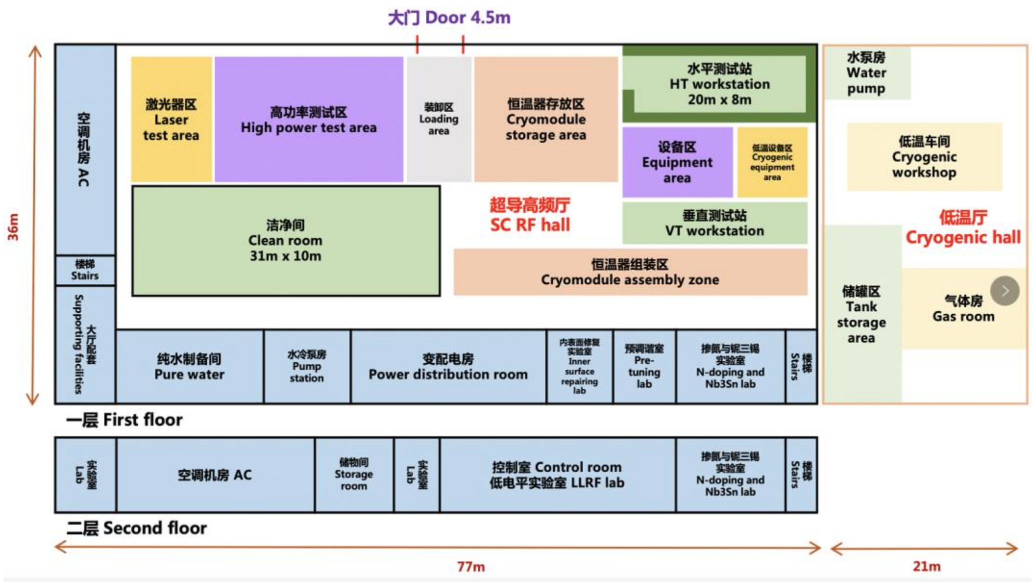
650 MHz 1+1 CMs
(CEPC 2/6x2-cell)

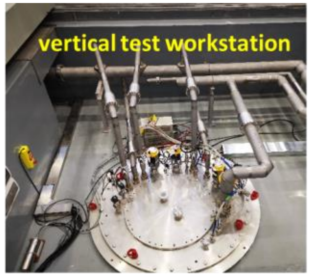
324 MHz 1+9 CMs
(CSNS-II 2xDSR)

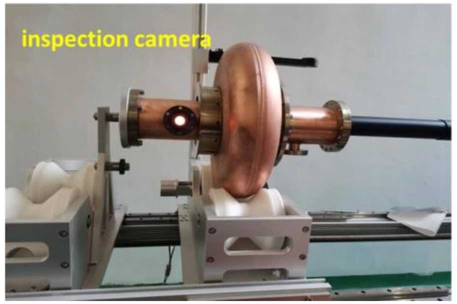


648 MHz +8 CMs
(CSNS-II 3x6-cell)

IHEP Dongguan SRF Infrastructure







Summary

- 20 years blooming SRF accelerator R&D at IHEP, we are in a golden era of large SRF accelerator facilities design and construction.
- Many challenges in the design, development, construction and operation of accelerators for the colliders, light sources & FELs and proton linacs.
- There is still a lot of room for the improvement of technological level.