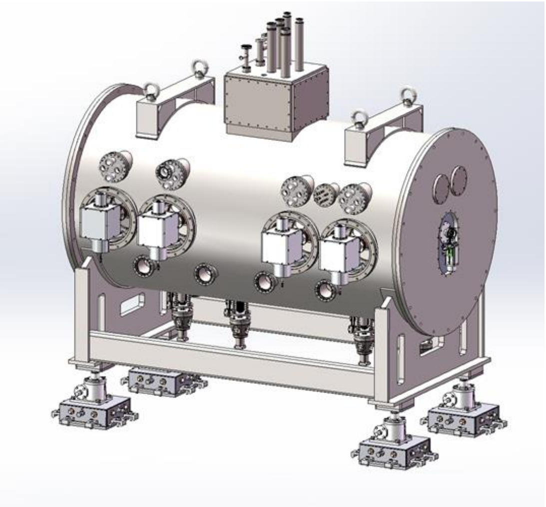
SRF project, team and infrastructure at IMP

Teng Tan, on behalf of IMP SRF team

2024-9-26



中华人民共和国科学技术部
Ministry of Science and Technology of the People's Republic of China

МИНИСТЕРСТВО НАУКИ
И ВЫСШЕГО ОБРАЗОВАНИЯ
РОССИЙСКОЙ ФЕДЕРАЦИИ

中国科学院
CHINESE ACADEMY OF SCIENCES

IMP

Joint Institute for Nuclear Research
SCIENCE BRINGS NATIONS TOGETHER

HIAF

NICA

Outlines

- Progress of existing collaboration project
- Plan for the next project
- Introduction about the infrastructure evolution at IMP
- Potential future collaboration directions

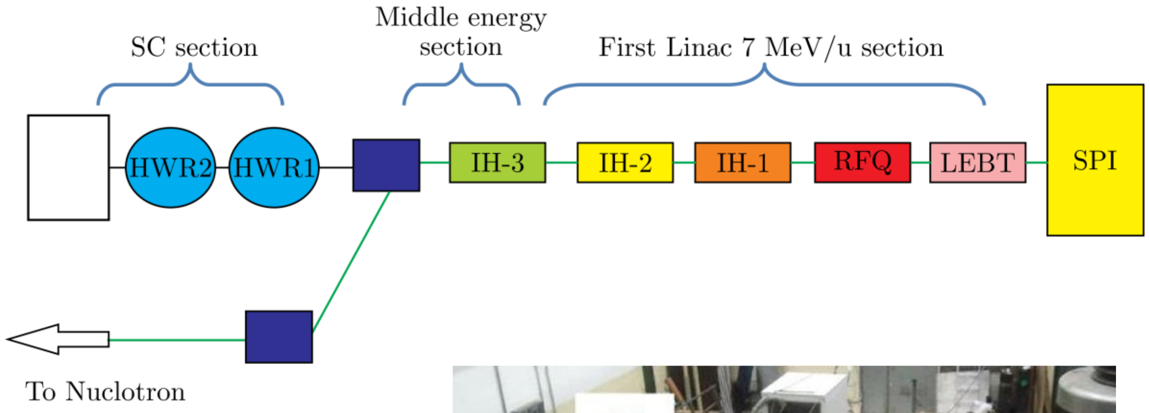
Outlines

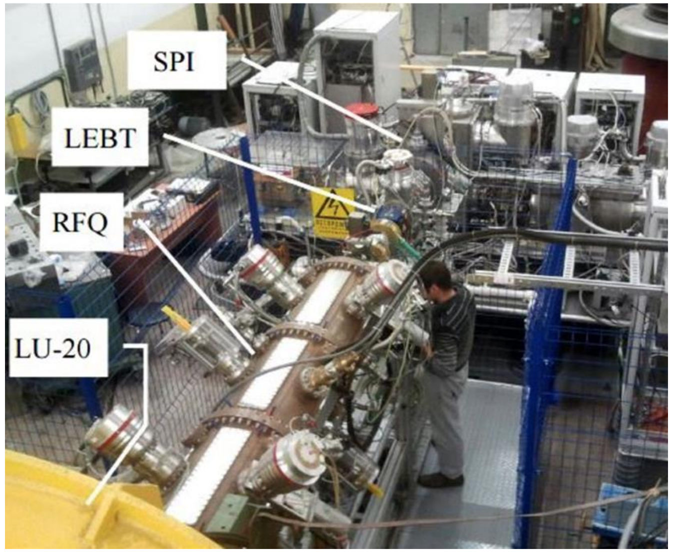
- Progress of existing collaboration project

The SRF cavities and the cryomodule

Original Motivation

- Current NICA Injector: normal conducting, RFT+IH, 7 MeV/u.
- Upgrade ongoing: 13 MeV proton with IH-3.
- SC upgrade: HWR-type cavity, SC section, 13 MeV/u to 30 MeV.
- Obstacles: the absence of entire SRF supply chain and experience in Russia
- IMP SRF team: runs heavy ion linac with the highest cw beam power over the world.





A. Butenko, RuPAC2021, MOY01.

Collaboration foundation

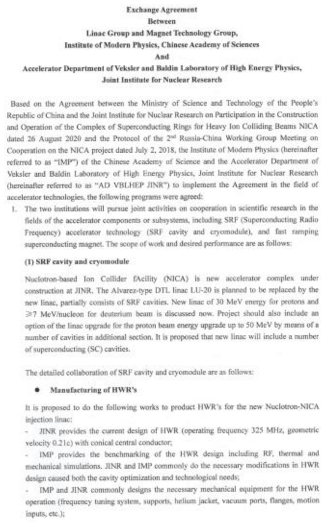
2018: MOU between China and Russian Government

2020.6: National Key Research and Development Program of China issued by China Ministry of Science and Technology. Funding collaborations on heavy-ion Linac related key technologies. Collaboration between IMP and JINR on SRF is one of them.

2021.8: Mutual agreement on collaboration signed by IMP and JINR. Collaboration targets an resources were clarified.

2021.12.24: Recurring video group meeting started.

2022-2023: 9 video meetings and JINR in-person visit.



Exchange Agreement
Between
Linac Group and Magnet Technology Group,
Institute of Modern Physics, Chinese Academy of Sciences
And
Accelerator Department of Veksler and Baldin Laboratory of High Energy Physics,
Joint Institute for Nuclear Research

Based on the Agreement between the Ministry of Science and Technology of the People's Republic of China and the Joint Institute for Nuclear Research on Participation in the Construction and Operation of the Complex of Superconducting Rings for Heavy Ion Colliding Beams NICA dated 26 August 2020 and the Protocol of the 2nd Russia-China Working Group Meeting on Cooperation on the NICA project dated July 2, 2018, the Institute of Modern Physics (hereinafter referred to as "IMP") of the Chinese Academy of Science and the Accelerator Department of Veksler and Baldin Laboratory of High Energy Physics, Joint Institute for Nuclear Research (hereinafter referred to as "AD VBLHEP JINR") to implement the Agreement in the field of accelerator technologies, the following programs were agreed:

1. The two institutions will pursue joint activities on cooperation in scientific research in the fields of the accelerator components or subsystems, including SRF (Superconducting Radio Frequency) accelerator technology (SRF cavity and cryomodule), and fast ramping superconducting magnet. The scope of work and desired performance are as follows:

(1) SRF cavity and cryomodule

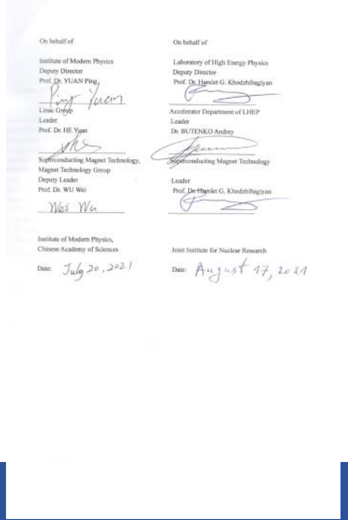
Nuclotron-based Ion Collider fAcility (NICA) is new accelerator complex under construction at JINR. The Alvarez-type DTL linac LU-20 is planned to be replaced by the new linac, partially consists of SRF cavities. New linac of 30 MeV energy for protons and ≥7 MeV/nucleon for deuterium beam is discussed now. Project should also include an option of the linac upgrade for the proton beam energy upgrade up to 50 MeV by means of a number of cavities in additional section. It is proposed that new linac will include a number of superconducting (SC) cavities.

The detailed collaboration of SRF cavity and cryomodule are as follows:

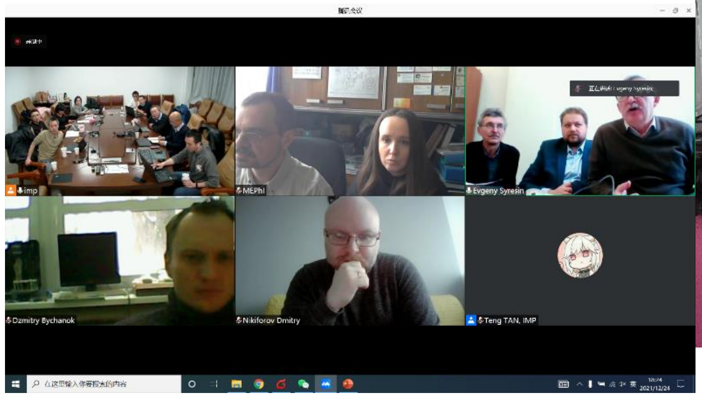
- **Manufacturing of HWR's**

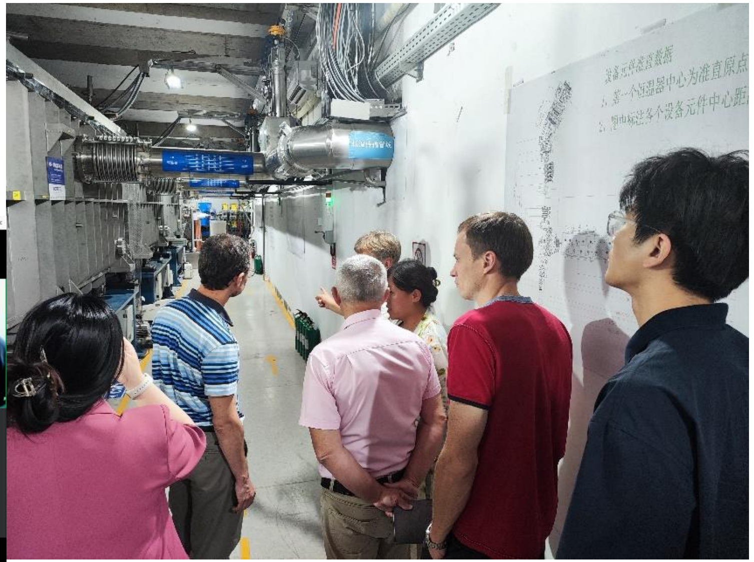
It is proposed to do the following works to product HWR's for the new Nuclotron-NICA injection linac:

- JINR provides the current design of HWR (operating frequency 325 MHz, geometric velocity 0.21c) with conical central conductor;
- IMP provides the benchmarking of the HWR design including RF, thermal and mechanical simulations. JINR and IMP commonly do the necessary modifications in HWR design caused both the cavity optimization and technological needs;
- IMP and JINR commonly designs the necessary mechanical equipment for the HWR operation (frequency tuning system, supports, helium jacket, vacuum ports, flanges, motion inputs, etc.);



On behalf of	On behalf of
Institute of Modern Physics Deputy Director Prof. Dr. YUAN Ping Ping Yuan	Laboratory of High Energy Physics Deputy Director Prof. Dr. Hamlet G. Khodzhibagiyan
Linac Group Leader Prof. Dr. HE Yuan	Accelerator Department of LHEP Leader Dr. BUTENKO Andrey
Superconducting Magnet Technology, Magnet Technology Group Deputy Leader Prof. Dr. WU Wei Wei Wu	Superconducting Magnet Technology Leader Prof. Dr. Hamlet G. Khodzhibagiyan
Institute of Modern Physics, Chinese Academy of Sciences Date: July 20, 2021	Joint Institute for Nuclear Research Date: August 17, 2021





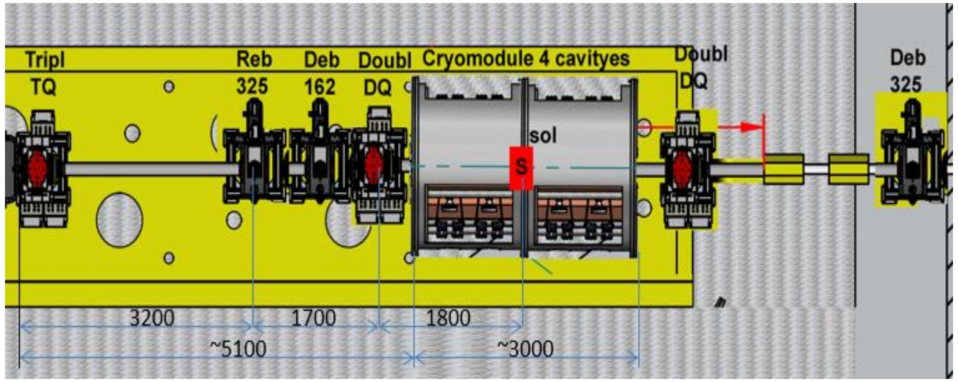
Project Targets

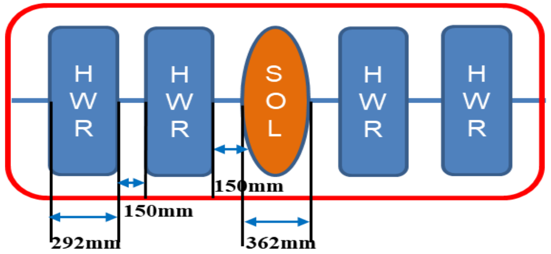
Key parameters:

- SRF Cavity: reach same level of the word-leading HI linacs.
- Help JINR SRF team develop their own SRF cavity fabrication, processing and test ability.
- Beam test on JINR site.

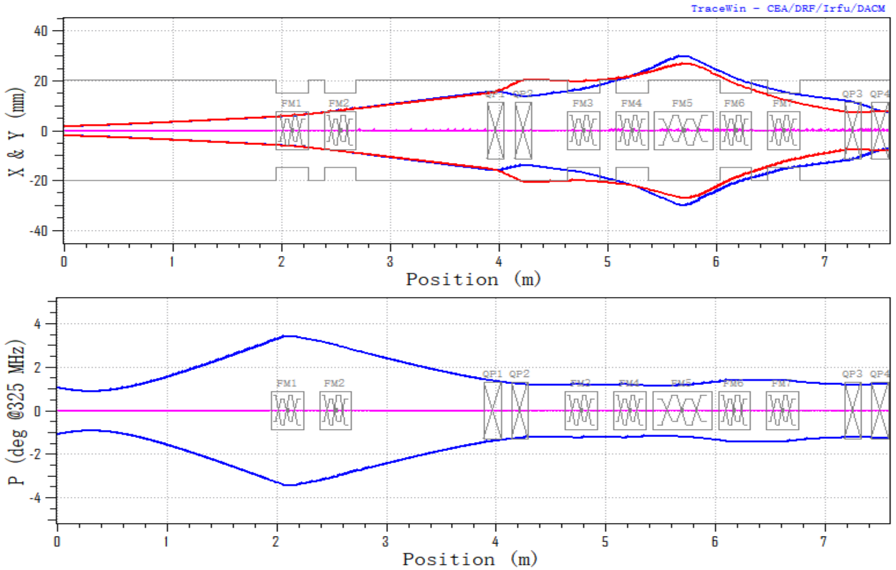
HWR Cavity	CAFe2 HWR010	CiADS HWR010	HIAF HWR015	CiADS HWR019	FRIB HWR029	FRIB HWR054	CiADS HWR040	NICA HWR021
Freq. /MHz	162.5	162.5	162.5	162.5	322	322	325	325
β_{opt}	0.10	0.10	0.15	0.19	0.29	0.54	0.40	0.21
E_{pk} /MV/m	26	26	28	28	33.3	26.5	28	30
Operation T/K	4.2	2	2	2	2	2	2	4.2
Operation mode	cw	cw	cw	cw	cw/pulsed	cw/pulsed	cw	cw/pulsed

Beam Dynamics

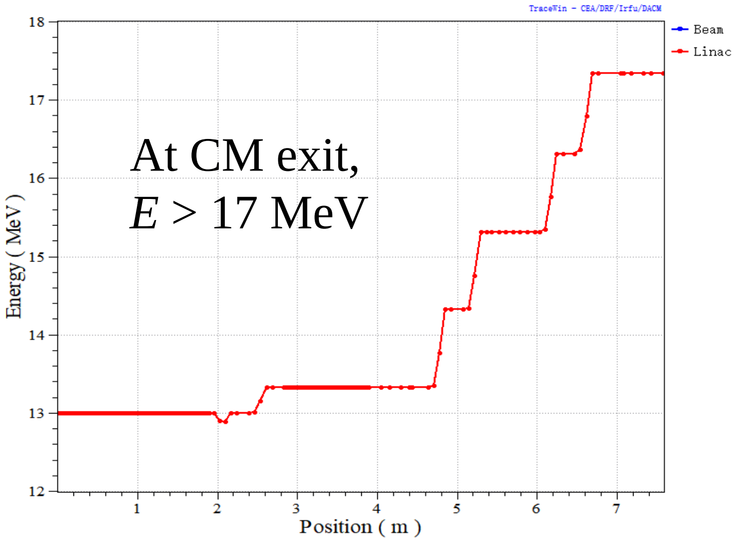




Physical layout



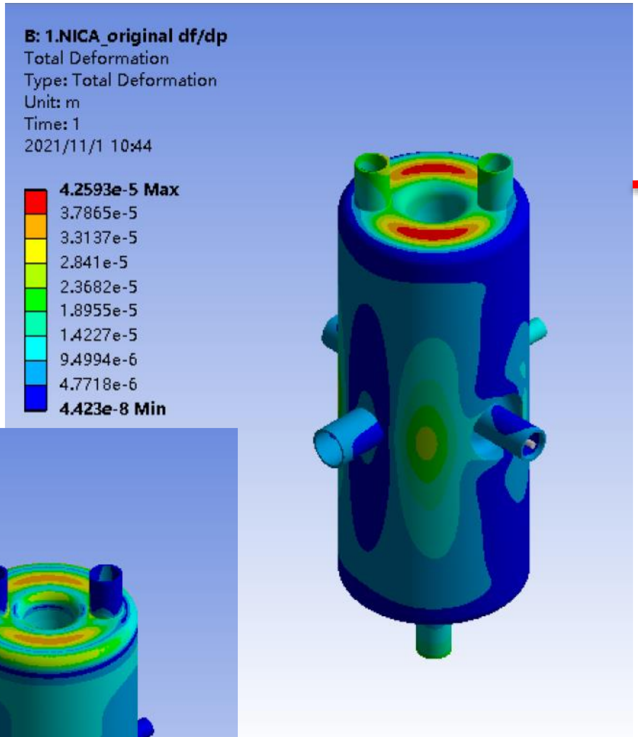
Beam transport:
5mA simulation results.



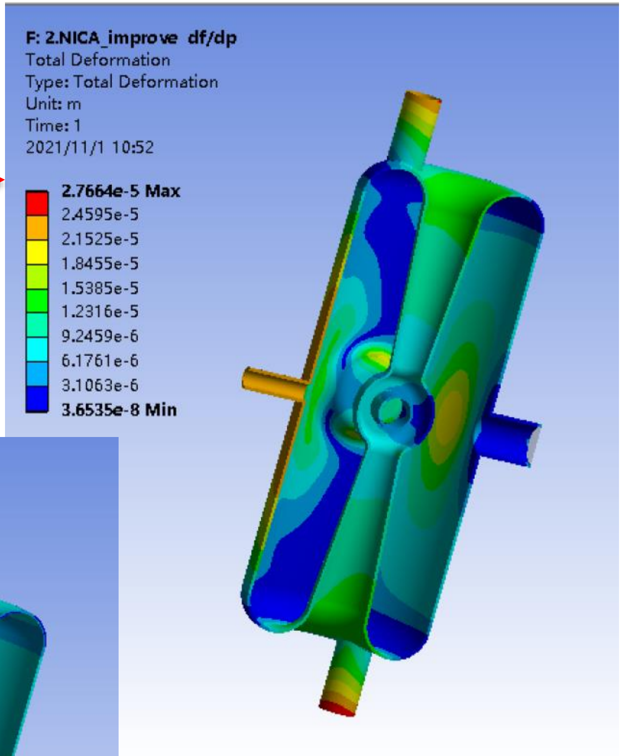
Lattice structure and final energy satisfy requirement.

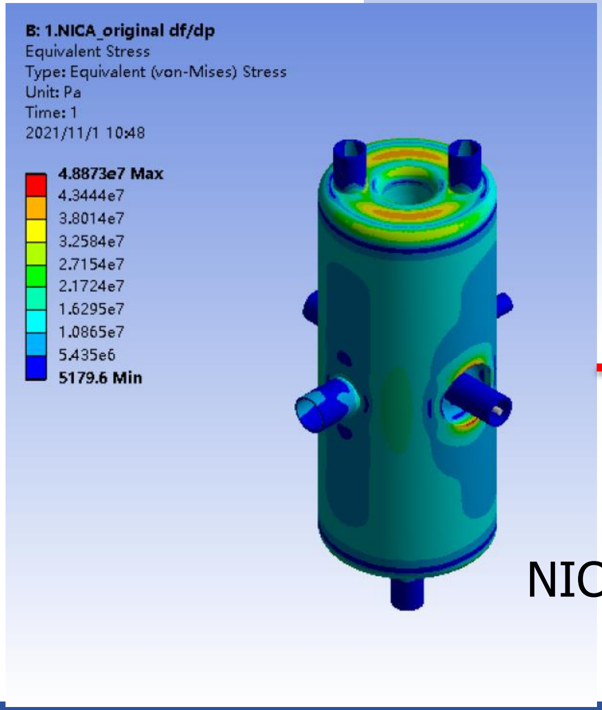
HWR021 SRF Cavity

IMP HWR021 design and optimization from the original design

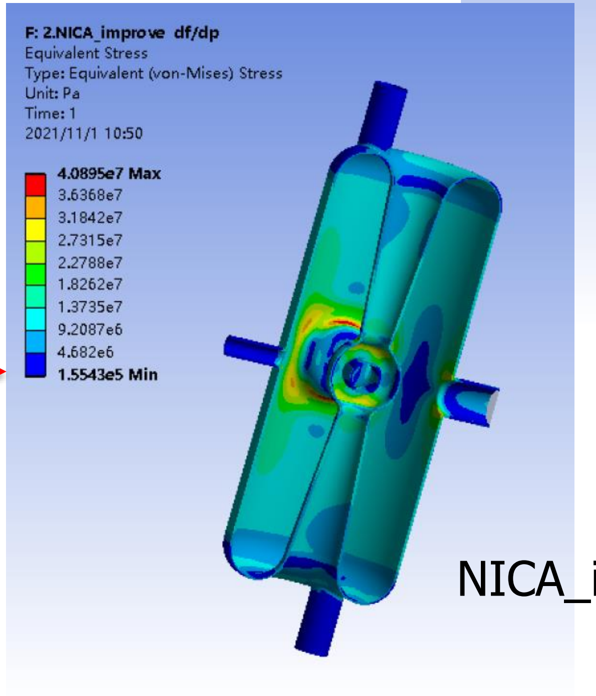


Reduced deformation





Reduced stress(20% less)

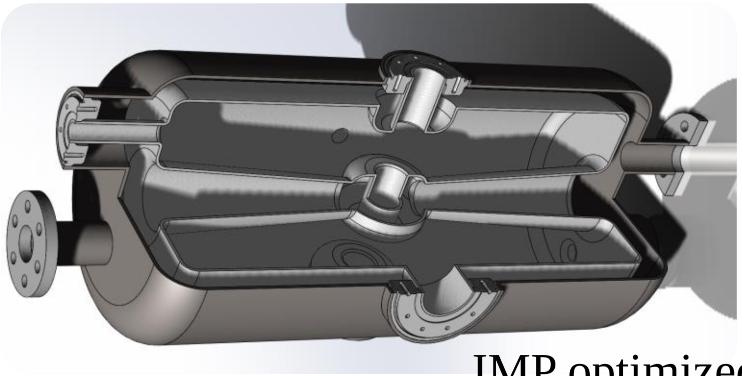


NICA_original model

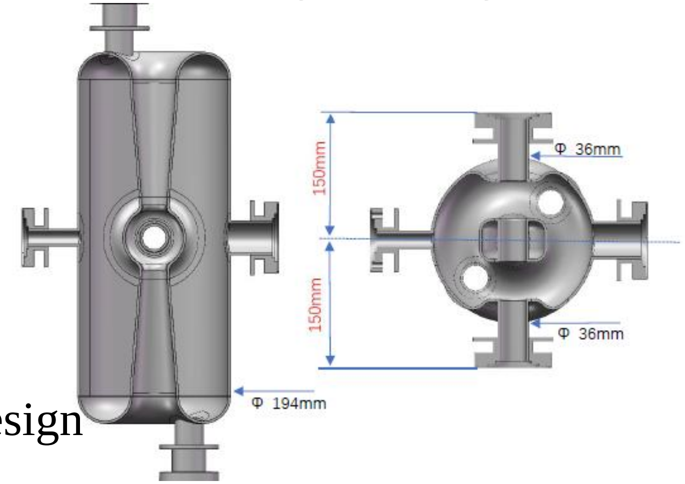
NICA_improved model

HWR021 SRF Cavity

IMP HWR021 design and optimization from the original design

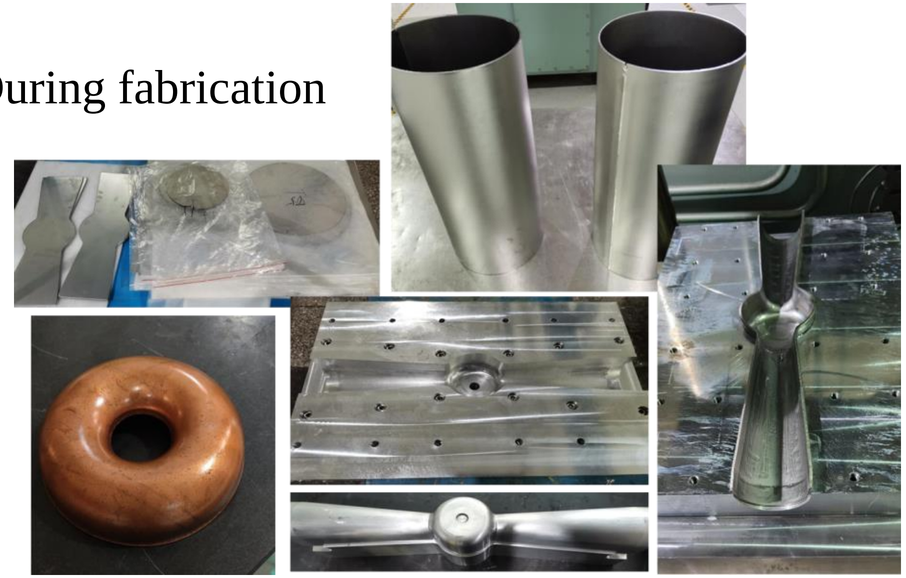


IMP optimized design

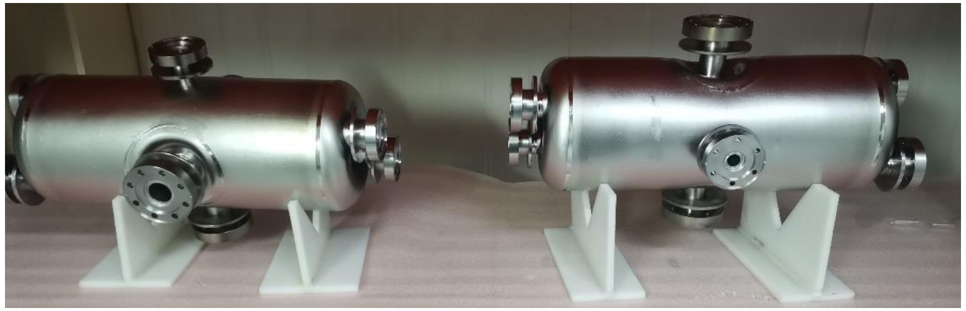


Cavity Processing

During fabrication



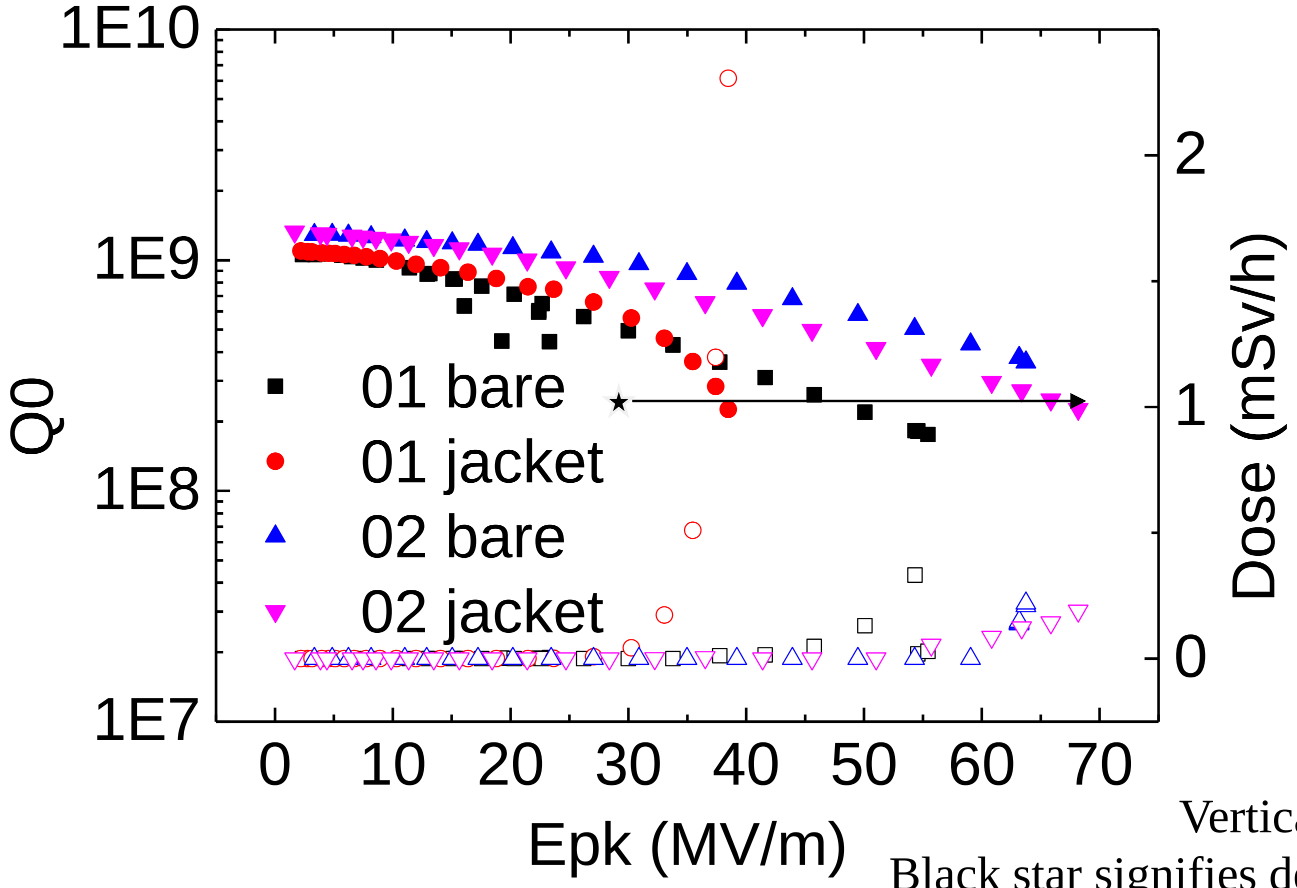
Final products
Without helium vessel



With helium vessel

Cavity vertical tests

Both cavities were tested in bare and jacketted conditions and all passed the test. 01 cavity with helium jacket showed inferior properties due to CSNS protocol change. Cavity was reprocessed.



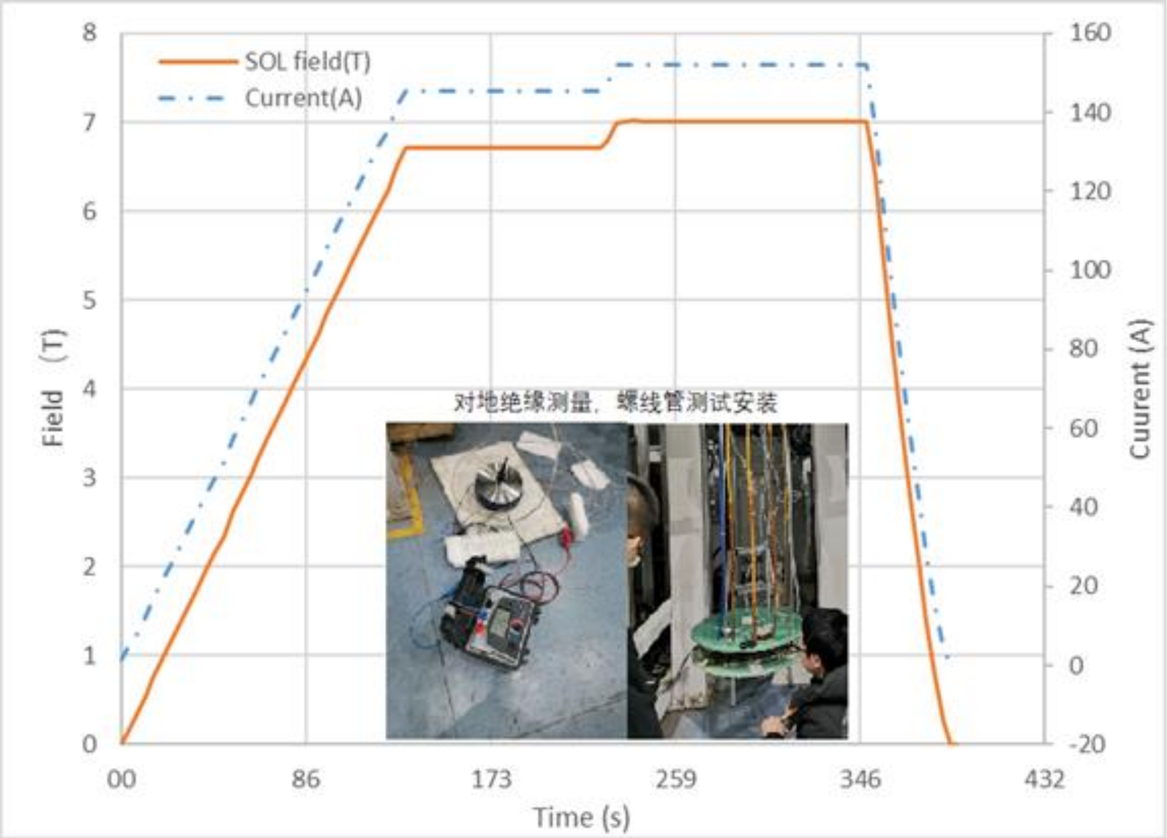
Vertical test results.
Black star signifies designed operation parameter.

Vertical test

Solenoids

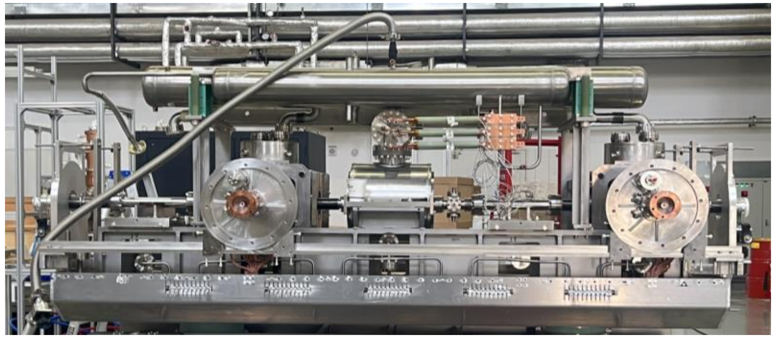
Both solenoids were manufactured and tested.

Solenoids cores and final products

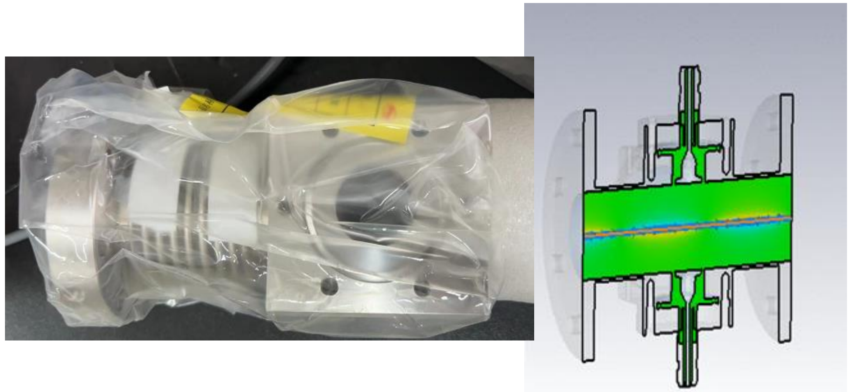


Solenoid test results

Others



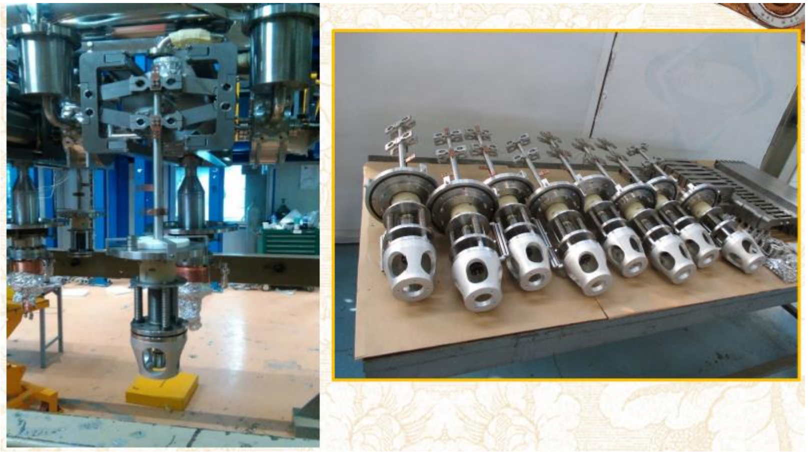
Coldmass



Beam Position Monitor (BPM)

Power supply for solenoid

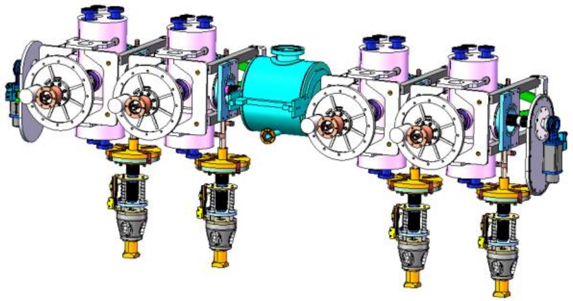
Fundamental Power Couplers



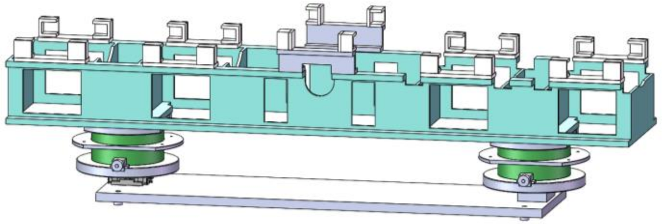
Tuners

RF amplifier for cavities

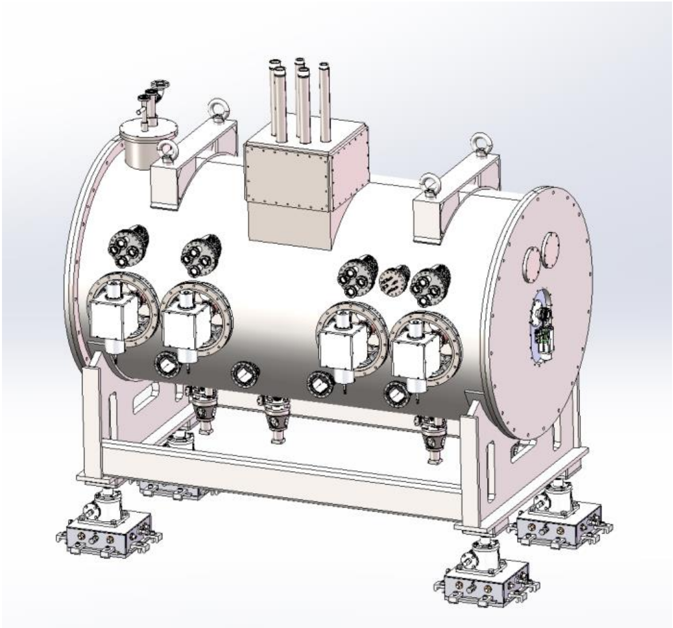
Cryomodule



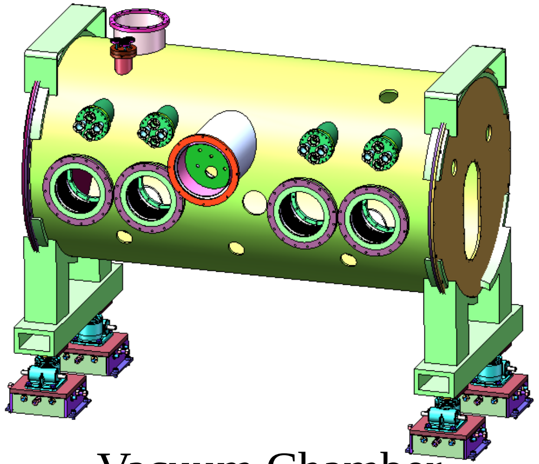
Coldmass



Coldmass frame



CM assembly

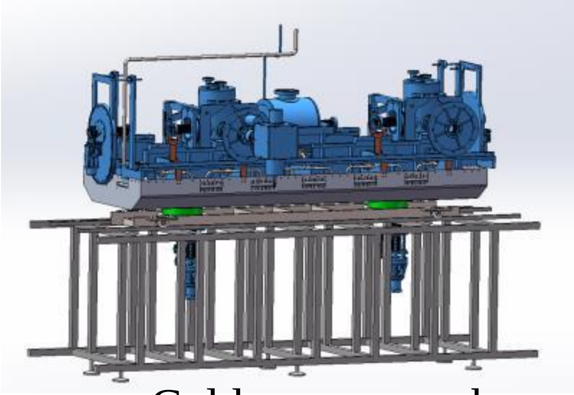


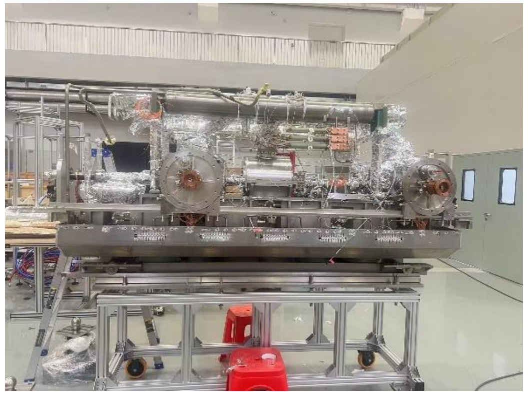
Vacuum Chamber

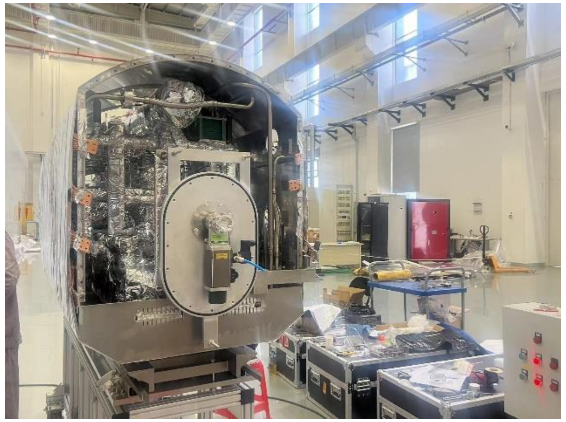
Cryomodule

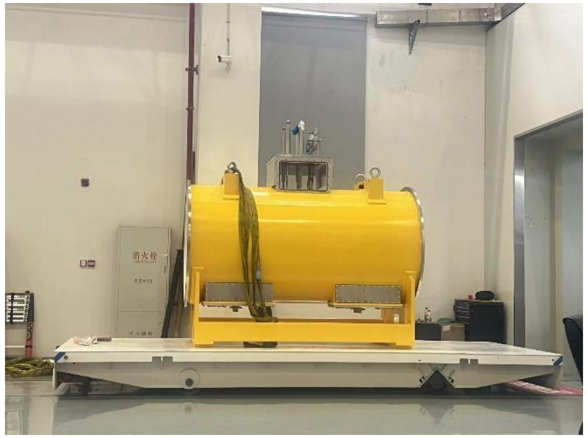

Coldmass inside cleanroom


Coldmass outside cleanroom (baking)


Coldmass on rack


Tubing installation


MLI and thermal shield


Transfer in bunker

Horizontal test plan

Vacuum spring replaced by vendor, delayed the first cooldown to October.

Horizontal test includes the thermal performance of the cryomodule, RF and mechanical performance of the cavities, and the magnet.

Test station is ready.

Outlines

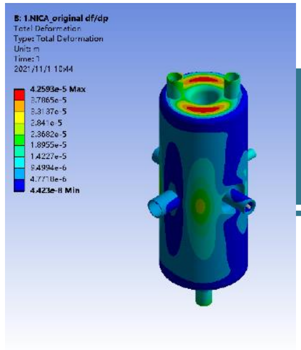
- Plan for the next project

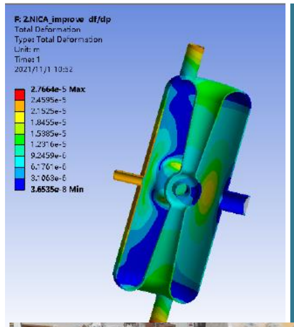
Outlines

- Plan for the next project

CM delivery and infrastructure

Roadmap in the new project





Fulfill the current CM on IMP side

2 new cavities

LLRF with automatic loading and recovery

Infrastructure and ability on JINR side

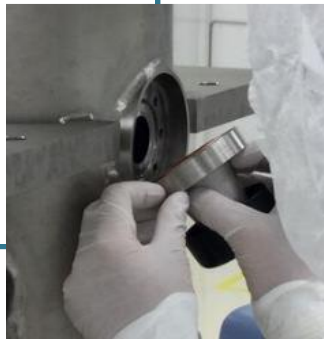
Cleanroom

Test stand

Delivery and re-commission

Parts and equipment delivery

Re-assemble and re-commission



Fulfill the current CM

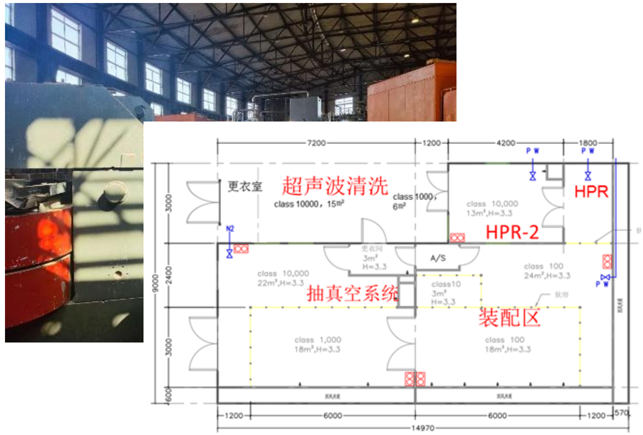
Cavity: optimize from current design

Good starting point for new SRF scientist

LLRF: auto-load and auto-recover in 3 mins for operating cavity

User-friendly and reduce the burden for continuous operation

Infrastructure and ability @ JINR



Clean room: design philosophy, workflow, lessons and experiences

Equipment: clean-related, water related, vacuum related

Personnel: visit, exchange, training

Able to open and re-assemble the delivery

Vertical test station: based on current 1-cavity cryostat

Collaboration on method, equipment, and personnel.

Perform cavity vertical test

Delivery and re-commission

- Custom documents requires a lot of paperwork.
- Sensitive devices need special process.
- China MOST project requires operation with beam.

ADDENDUM #1
to
MEMORANDUM FROM 08.10.2016
between
Joint Institute for Nuclear Researches (JINR)
and
Institute of modern physics of Chinese Academy of Science (IMP CAS)
concerning
Research and Development for NICA and HIAF projects, nuclear and accelerator science, theory and technologies and other scientific domains of mutual interest

In the frame of Memorandum of cooperation and joint research activities in the field of development and creation of an accelerator complex of superconducting rings on colliding beams of heavy ions NICA, according to the NICA project, the parties agreed on the following:

To carry out the collaborative research JINR transfers to IMP CAS the following equipment:

№	Name of equipment	unit.	Number of units	Price, USA dollars	Total cost, USA dollars
1	Prototype half-wave resonator № 515726	ps.	1	265 000.00	265 000.00
	Total:				**265 000.00***

*The cost of the equipment is indicated only for customs purposes and is not subject to payment.

Delivery conditions: **DAP – Huizhou** INCOTERMS 2020
Equipment transportation is carried out at **JINR** expenses.

Addendum for cavity shipping

Outlines

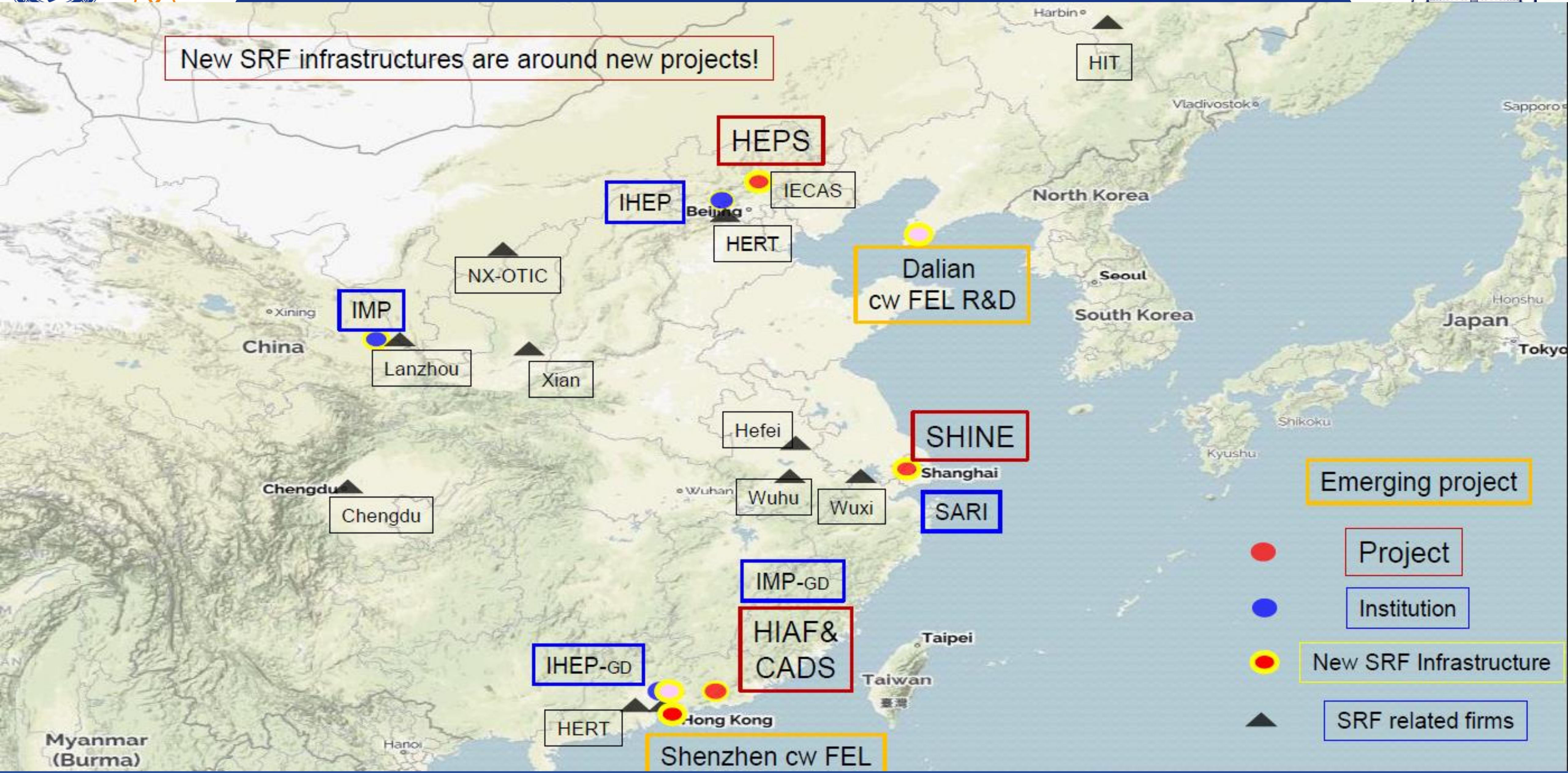
- Introduction about the infrastructure evolution at IMP

Outlines

- Introduction about the infrastructure evolution at IMP

HIAF, CiADS, IP-SAFE and others

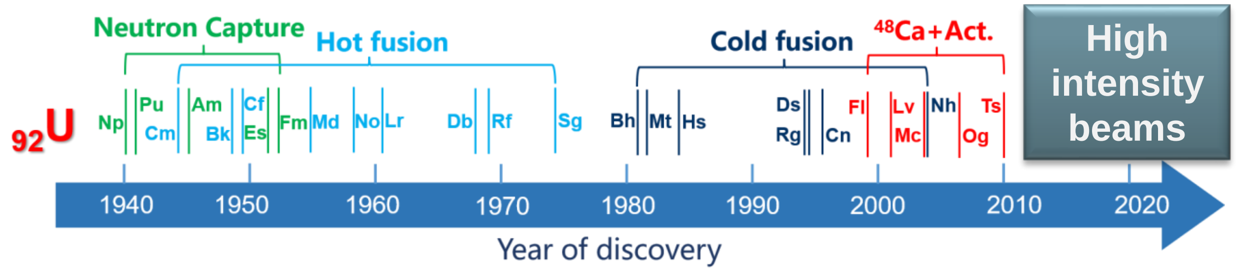
1. CAFE2

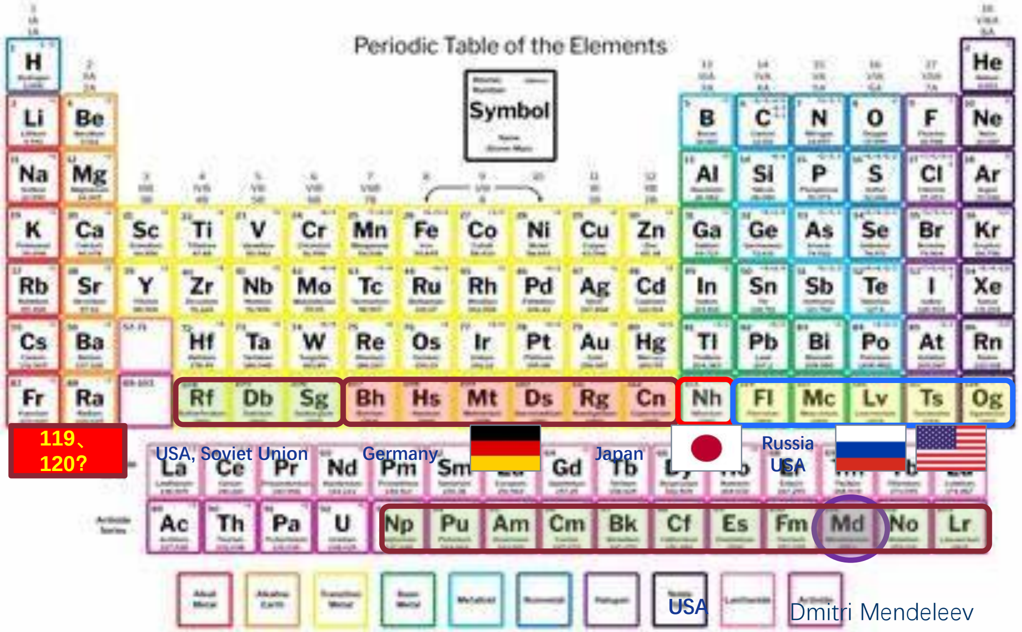

New SRF infrastructures are around new projects!
HEPS
IECAS
IHEP
Beijing
HERT
NX-OTIC
IMP
Xining
China
Lanzhou
Xian
Dalian
cw FEL R&D
Harbin
HIT
Vladivostok
Sapporo
North Korea
Seoul
South Korea
Japan
Honshu
Tokyo
Shikoku
Kyushu
Hefei
SHINE
Shanghai
SARI
Chengdu
Chengdu
Wuhan
Wuhu
Wuxi
IMP-GD
HIAF&
CADS
IHEP-GD
HERT
Hong Kong
Taipei
Taiwan
Hanoi
Myanmar
(Burma)
Shenzhen cw FEL
Emerging project
Project
Institution
New SRF Infrastructure
SRF related firms

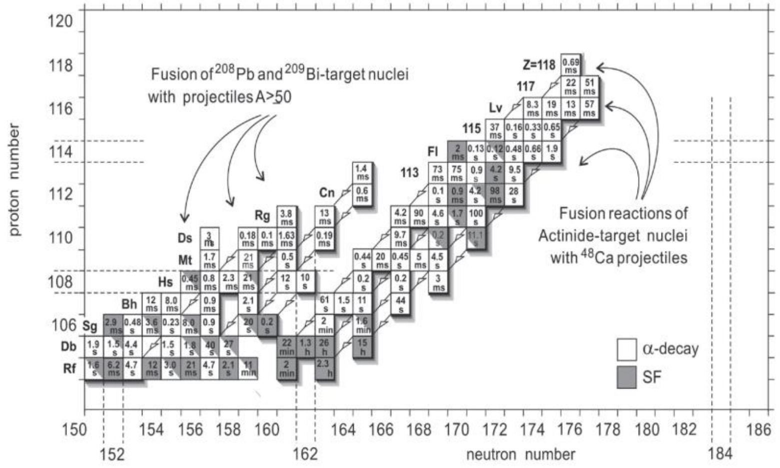
CAFe2 Objects-Superheavy Elements (Z>103)

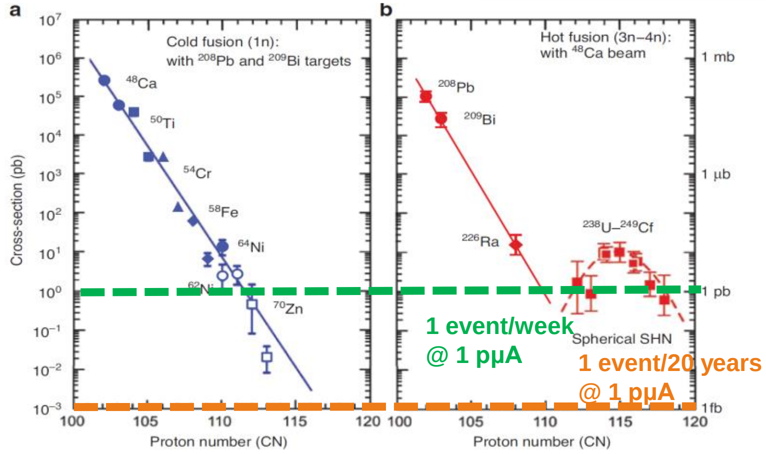
Top science questions：

How many elements can exist on Periodic Table?
Are there stable high-atomic-number elements?
What are their chemistry properties for the heaviest elements?









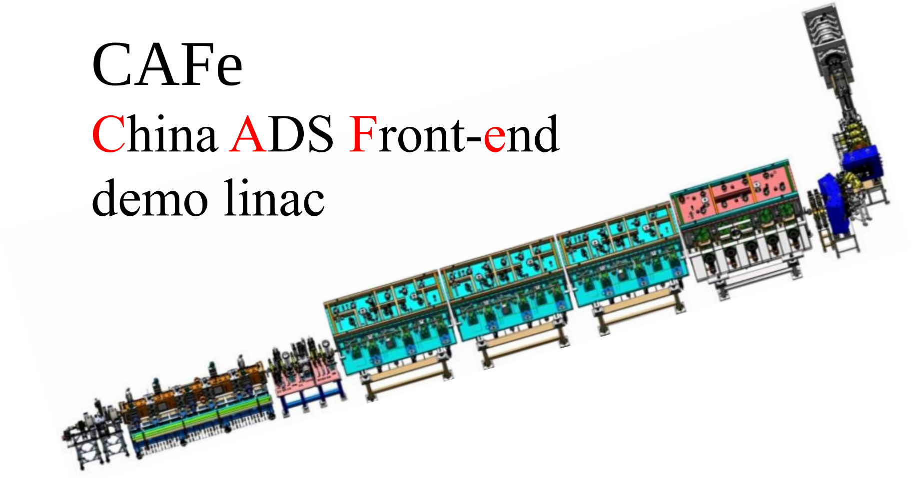
S. Hofmann, in *Radiochimica Acta* **107**, 879 (2019).

- ***Challenges:***
  - High beam intensity with Ca~Zn ions (5~10 pμA)
  - Long beam time (a few months or years expt.)
  - Actinide target material (U, Am, Cm, Cf ···)
  - Rotating target withstanding high power beams
  - High efficiency separator
  - Atom-at-a-time detection and DAQ

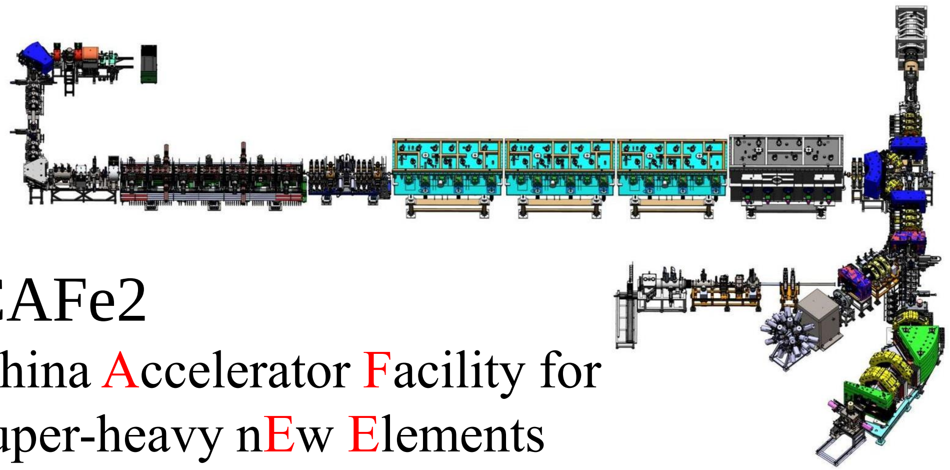
Evolution from CAFe to CAFE2

CAFe

China ADS Front-end demo linac



Commission stage	First CW beam	Max Energy (MeV)	Beam time (hours)	CW beam time Total (hours)	Max CW Current (mA)	Max CW Power (kW)
RFQ	Jun. 21, 2014	2.15	2036	90/~120	11	23
TCM1	Nov. 24, 2014	2.55	208	22.5	11	28
TCM6	Jun. 24, 2015	5.3	400	20	4	21
INJECT II	Sep. 24, 2016	10.2	327	11	2.7	26
CAFE	Jun. 7, 2017	26.1	~600	~140	10	200
CAFE2	Feb. 6, 2022	4.5~7 MeV/u	>5000	>3000	A/q < 3, 5 puA	



CAFe2

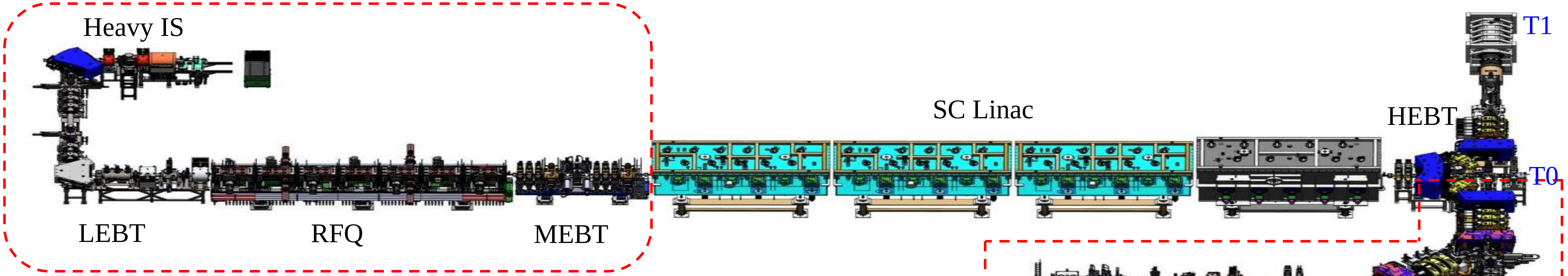
China Accelerator Facility for super-heavy nEw Elements

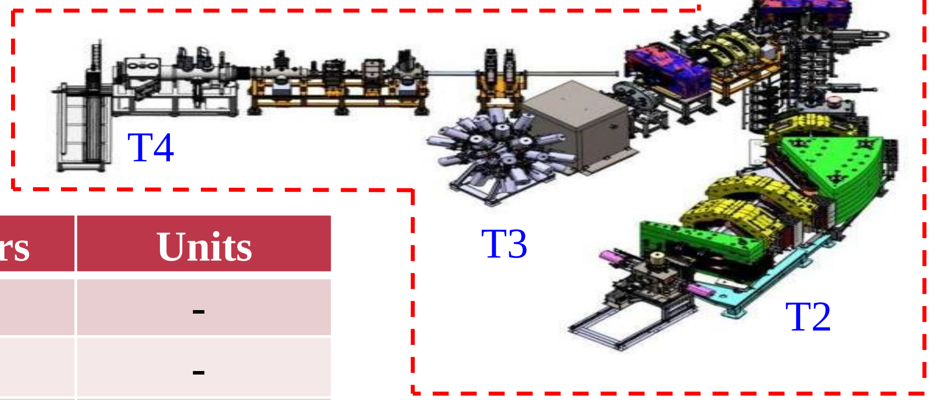
Commissioning campaigns

1. **Mar. 2021, CAFe achieved nominal specification, CW beam**
   - **20 MeV, 10 mA, 200kW, Proton;**
   - **17.3 MeV, 7.2 ~ 10 mA, 174 kW, 120 h.**
2. **2022.02.06, CAFE2 first beam.**

   2022.03—now, user experiments

CAFE2 Upgrades





➢ Accelerator:

ECR ion source
Low energy beam transfer (LEBT)
Radio frequency quadrupole (RFQ)
Medium energy beam transfer (MEBT)
High energy beam transfer (HEBT)

➢ Terminal:

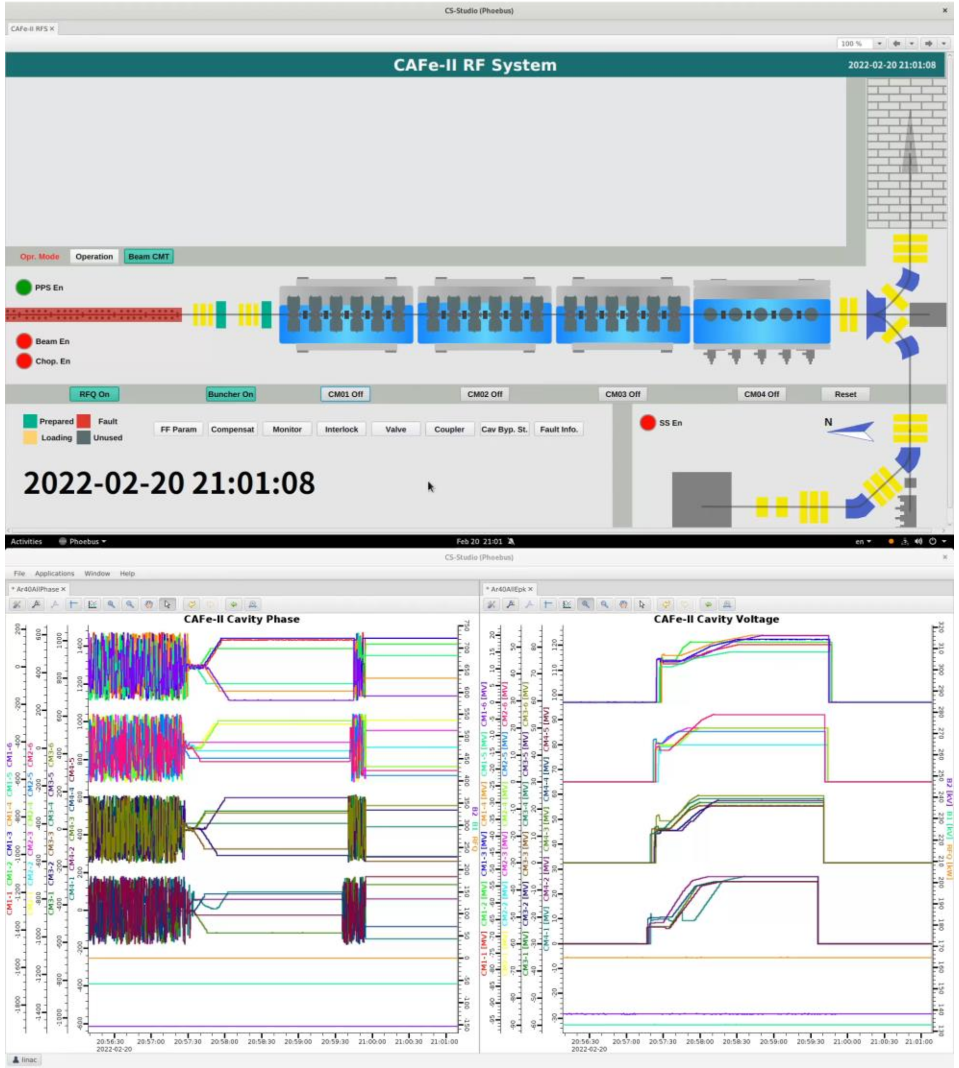
T0: Beam commissioning
T1: High power beam dump
T2: Spectrometer for Heavy Atoms and Nuclear Structure (SHANS2)
T3: Low power irradiation
T4: Proton Radiation Effects (PRE)

	Parameters	Parameters	Units
Ions	Ca～Zn	P/He	-
A/q	3	1/2	-
Energy	4.0-6.5	20/10	MeV/u
Current	1~10	1000	puA
Modes	Pluse/CW	Pluse/CW	-

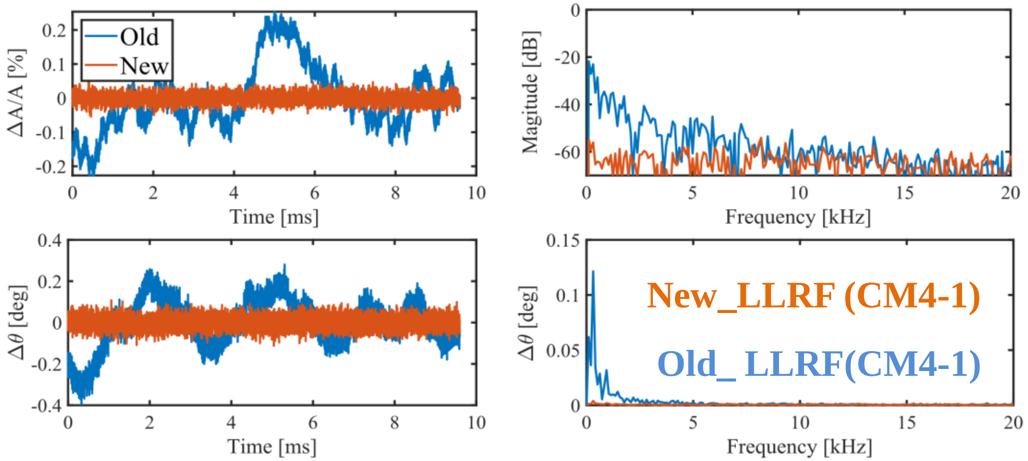
Goals:

- ➢ **Highest beam current accelerator for superheavy elements synthesis**
- ➢ **Engaging in research on the synthesis of the 119th and 120th element**

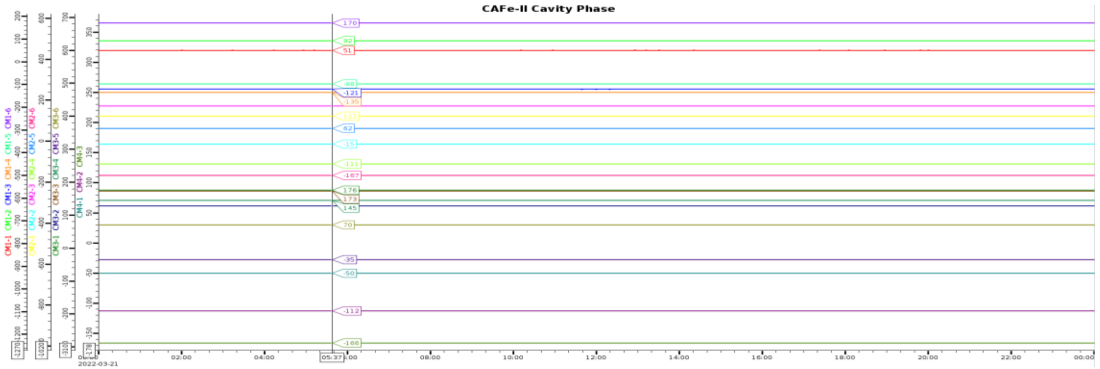
CAFE2 SCL Stablity



Cavity auto turn-on and recovery



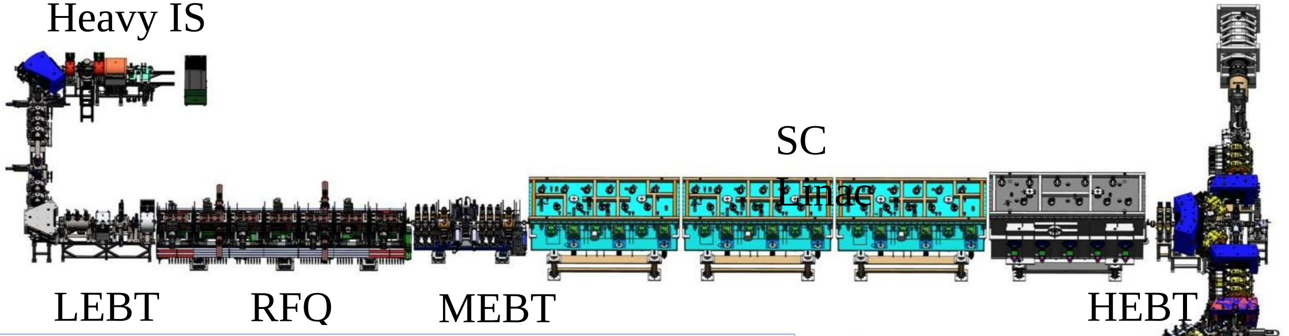
Amplitude and phase errors:(0.02%， 0.04 deg）@10mA



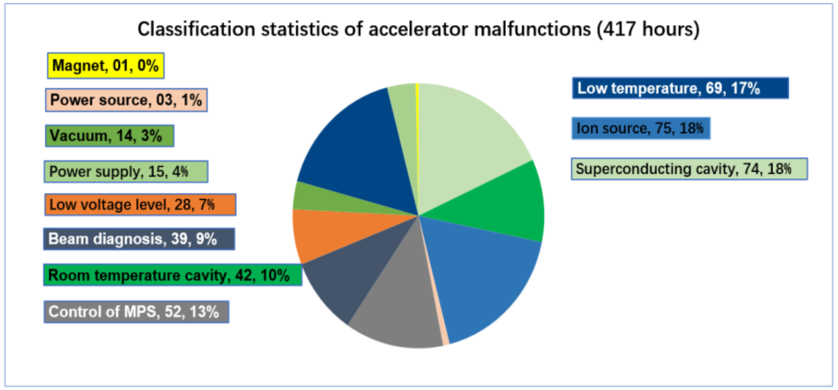
CAFE2 23 SC cavities in close loop（24 hours）

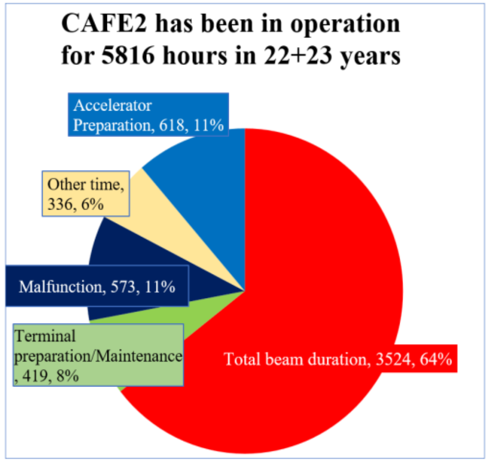
- The auto on and recovery feature was developed for all CAFE2 cavity
- The stability of SC cavity was significantly improved with the new LLRF

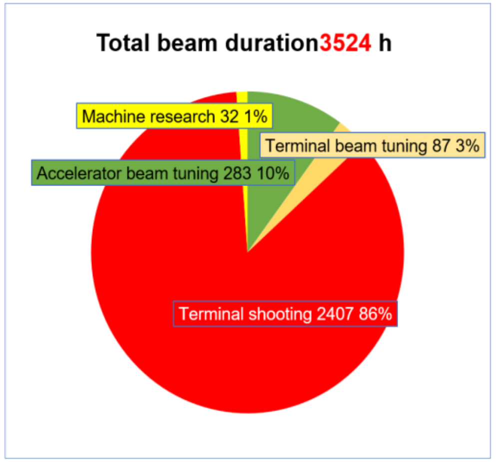
CAFE2 Operation Records

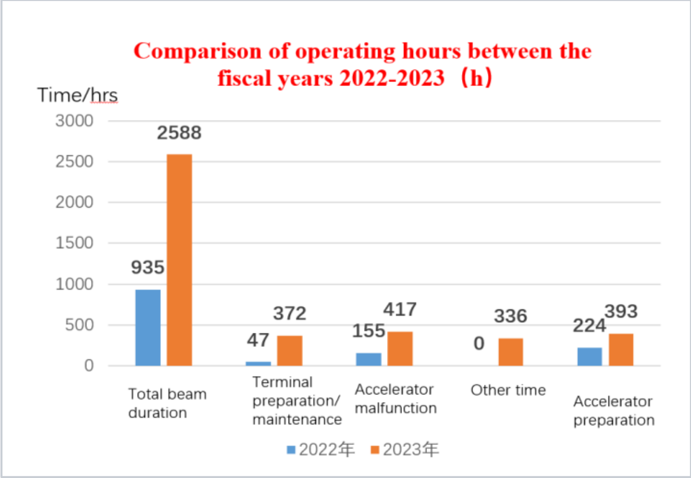


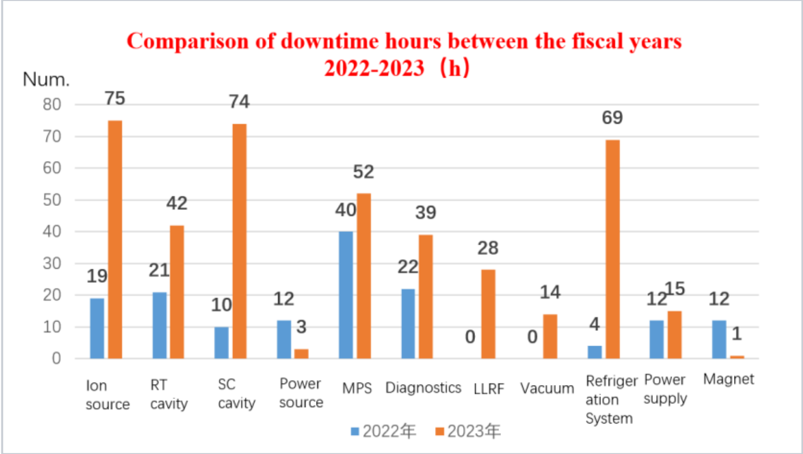
Statistics of SHANS Experiment Time (2022 ~2023)					
Particle	Accumulated Beam Hours	Targeting Hours	**Particle**	Accumulated Beam Hours	Targeting Hours
40Ar13+	248	248	**40Ar12+**	1302	1287
40Ca13+	962	717	**48Ca14+**	410	384
55Mn17+	232	134	**54Cr17+**	859	816
>90% Availability!					





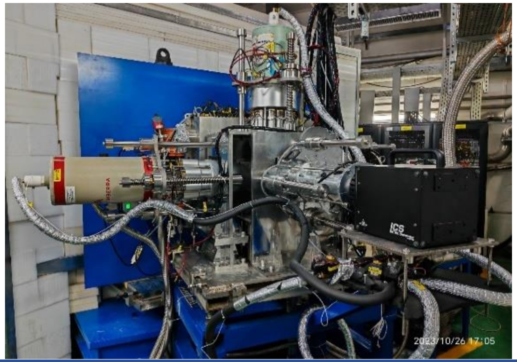






CAFe2 Recent Highlights

- **Superheavy ^{288}Mc produced on CAFE2**
- **$^{48}Ca^{14+} + {}^{243}Am \rightarrow {}^{291}Mc$**
- **Beam Time: July to Nov. 2023**
- **Beam on Target: 0.5~1 pμA**



NIMA: 168113 | Model 5G | pp. 1–8 (col. figs: 9)

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ELSEVIER

Full Length Article

A gas-filled recoil separator, SHANS2, at the China Accelerator Facility for Superheavy Elements

S.Y. Xu [a,b], Z.Y. Zhang [a,b,*], Z.G. Gan [a,b,c], M.H. Huang [a,b], L. Ma [a], J.G. Wang [a], M.M. Zhang [a], H.B. Yang [a], C.L. Yang [a], Z. Zhao [a,b], X.Y. Huang [a,b], L.X. Chen [a,d], X.J. Wen [a,d], H. Zhou [a,b], H. Jia [a], L.N. Sheng [a], J.Q. Wu [a], X.L. Peng [a], Q. Hu [a], J. Yang [a], Q.G. Yao [a,b], Y.S. Qin [a], H.H. Yan [a], Z. Chai [a,b], J.C. Zhang [a], Y. Zhang [a], Z. Du [a], H.M. Xie [a], B. Zhao [a], G.Z. Sun [a], F.F. Wang [a], C.Z. Yuan [a], X.L. Wu [a], R.F. Chen [a], H.B. Zhang [a], Z.W. Lu [a], H.R. Yang [a], X.X. Xu [a], Y.X. Chen [a], A.H. Feng [a], P. Sun [a], J.K. Xu [a], Y. He [a,b,c], L.T. Sun [a,b], X.H. Zhou [a,b], H.S. Xu [a,b,c], V.K. Utyonkov [e], A.A. Voinov [e], Yu.S. Tsyganov [e], A.N. Polyakov [e], D.I. Solovyev [e]

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[e] Joint Institute for Nuclear Research, Dubna, 141980, Russian Federation

Reaction^(55)Mn+^(159)Tb:preparation for the synthesis of new elements

The complete fusion reaction of^(55)Mn+^(159)Tb was studied on the gafilled recoil separator SHANS2.Nineteen ER-伪1-伪2 decay chains from^(210)Th produced ...

陈立欣，徐苏扬，张志远，... - 《中国物理c:英文版》

➢ ………………

2. CiADS

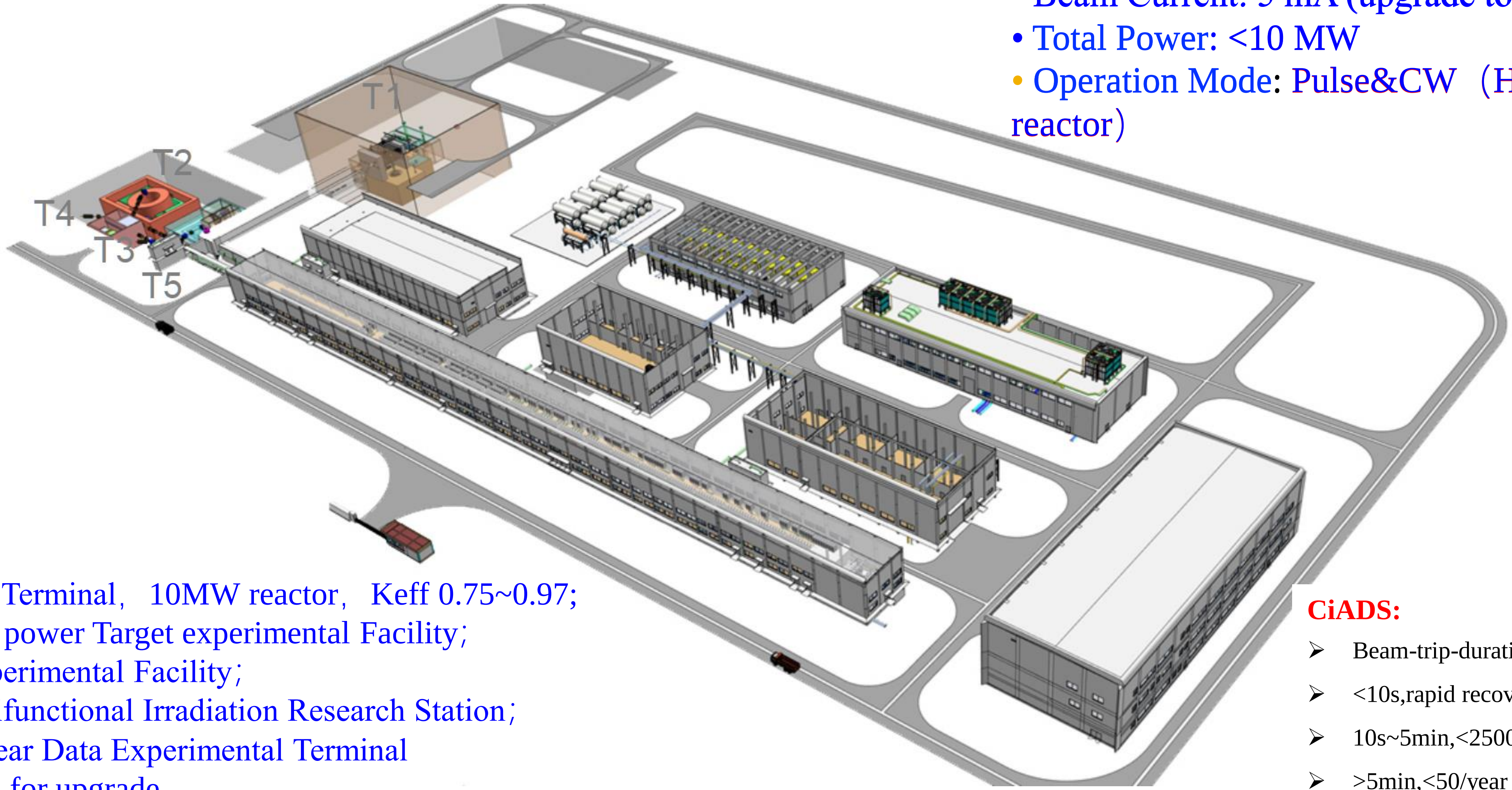
Brief introduction of CiADS project

- **Approved in Dec. 2015, Ground broke in August 2018, Officially started in July 2021**
- **Leading institute: IMP**
- **Budget: ~4 B CNY (Gov. 1.8B + CNNC 1.0 B + Local Gov. 1.2 B)**
- **Location: Huizhou, Guangdong Prov.**
- **Partners: CIAE, CGN, IHEP, etc.**

Brief introduction of CiADS project

The world's first MW-level ADS prototype

- Beam Energy: 500 MeV (upgrade to 1.5GeV)
- Beam Current: 5 mA (upgrade to 10 mA)
- Total Power: <10 MW
- Operation Mode: Pulse&CW （Has gap for reactor）



- T1: ADS Terminal, 10MW reactor, Keff 0.75~0.97;
- T2: High power Target experimental Facility;
- T3: μ experimental Facility;
- T4: Multifunctional Irradiation Research Station;
- T5: Nuclear Data Experimental Terminal
- T6: ISOL for upgrade

CiADS:

- Beam-trip-duration tolerance is 10s
- <10s,rapid recovery
- 10s~5min,<2500/year
- >5min,<50/year

CiADS superconducting linac

The overview design consideration

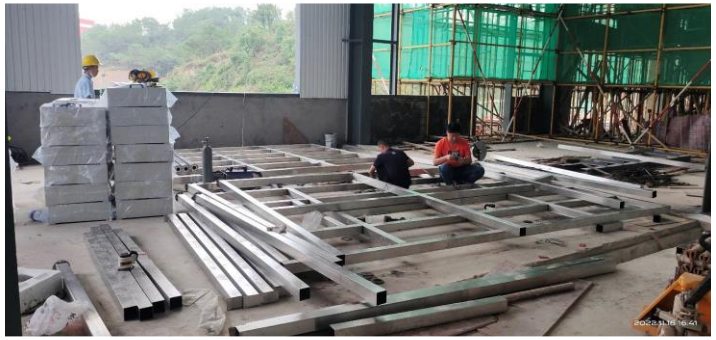
- RAMI - oriented
  - Redundancy design
  - Modular design
  - Fault-compensation scheme
  - Beam loss control
- Economy
  - High utility efficiency of Key components (cavity and SSA)
  - Well developed technology at IMP
  - More focus on the system integration and optimization (LLRF,ICS)
- Upgradeability
  - Energy ~1 GeV
  - Current ~ 10 mA

Main prameters of CiADS linac

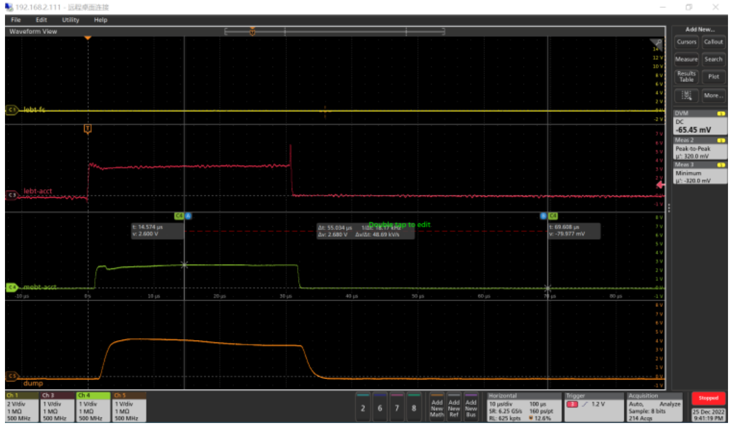
Particle	H^+	
Output energy	500	MeV
Beam current	5	mA
Beam power	2.5	MW
RF frequency	162.5/325/650	MHz
Cavity type	HWR010/019/040& Ellip062/082	-
Operation mode	CW&Pulse	-

CiADS superconducting linac

Beam commissioning





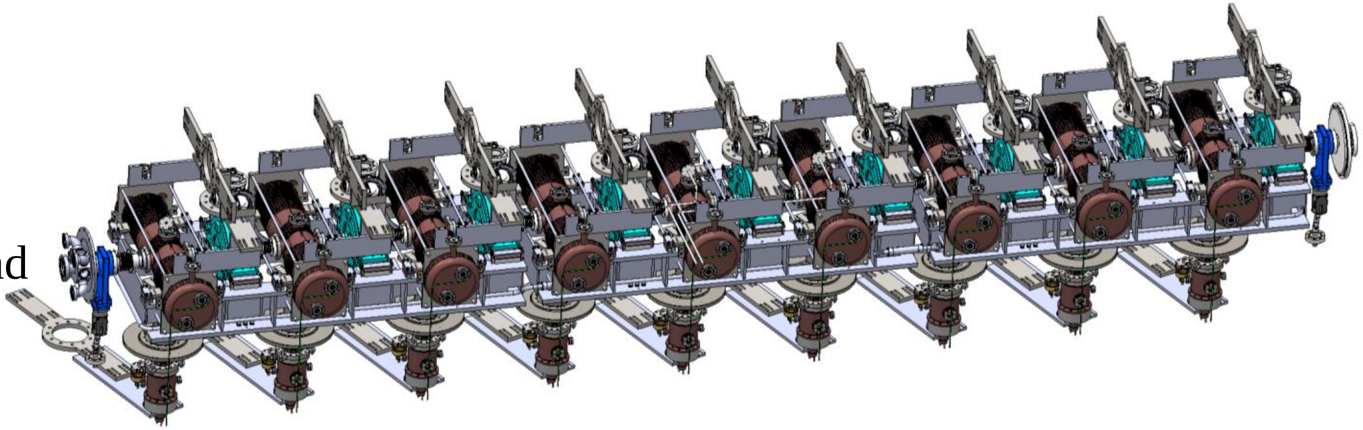
First beam of CiADS was commissioned in Dec. 2022, together with the construction of Huizhou Campus. Pulsed proton beam @ 2.18MeV, 5.2mA

CiADS superconducting linac

The world’s first composite HWR coldmass

First cold mass consisted of Nb/Cu cavities:
Assembled in IMP Huizhou Campus.

String was assembled with digital-twin assistance and semi-automatic clean assembling technique.



CiADS superconducting linac

The world’s first composite HWR cryomodule for HWR010

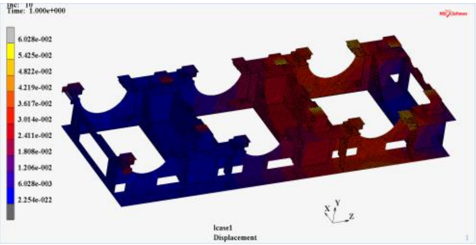
Nb/Cu cavities cooled by both LHe and conduction:

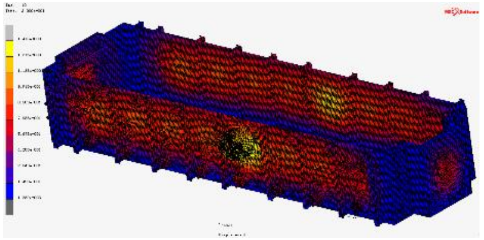
Design works:

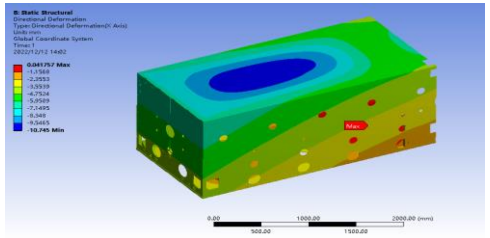
- Structure;
- Manufacture process;
- Pipelines;
- Heat load and LHe flow.

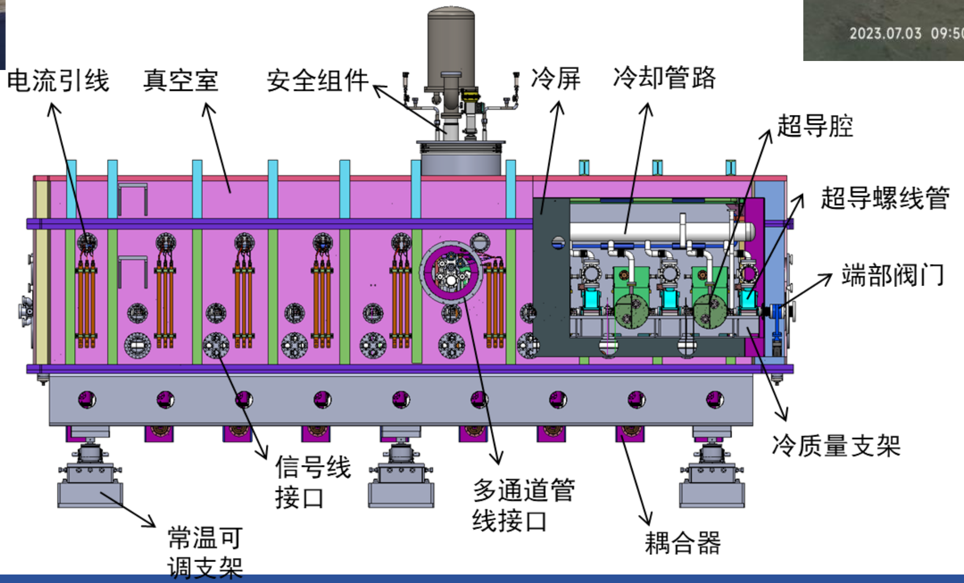
Manufacture works:

- Detailed manufacture plan;
- Pressure test;
- Thermal shock;
- Entire frame shipped to Huizhou.









HWR040 1mm-wall Nb/Cu Cavities

Multiphysics

Parts

Bare cavities

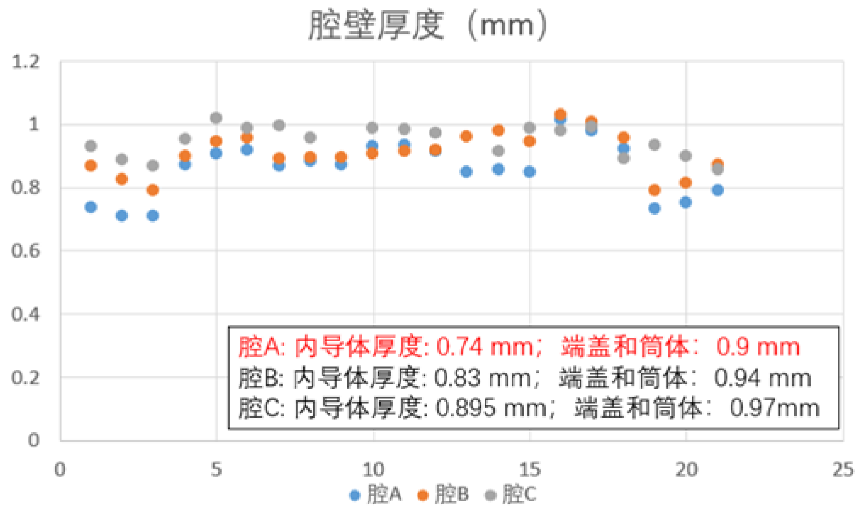
	Cavity A	Cavity B	Cavity C
Frequency (MHz)	325.07	325.58	325.56
Leak rate (mbar.l/s)	< 5.5E-6	< 6.1E-6	< 5.9E-6

Seeding layer

Electroplated copper

Final cavity

Cavity tuning



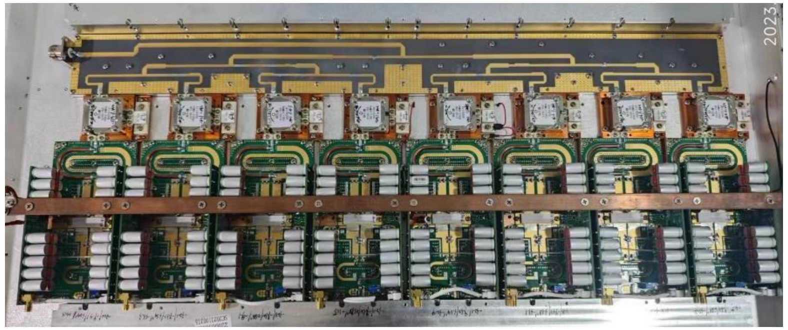
GaN Solid State Amplifier

A compact and highly reliable solid-state power source design is carried out by utilizing the advantages of GaN power devices such as high blocking voltage, high operating frequency, high temperature resistance, and low losses.

Development of P-band pulse SSA:
Single tube 5kW, 1 ‰ duty cycle;
25/50/100kW plugin debugging in progress.

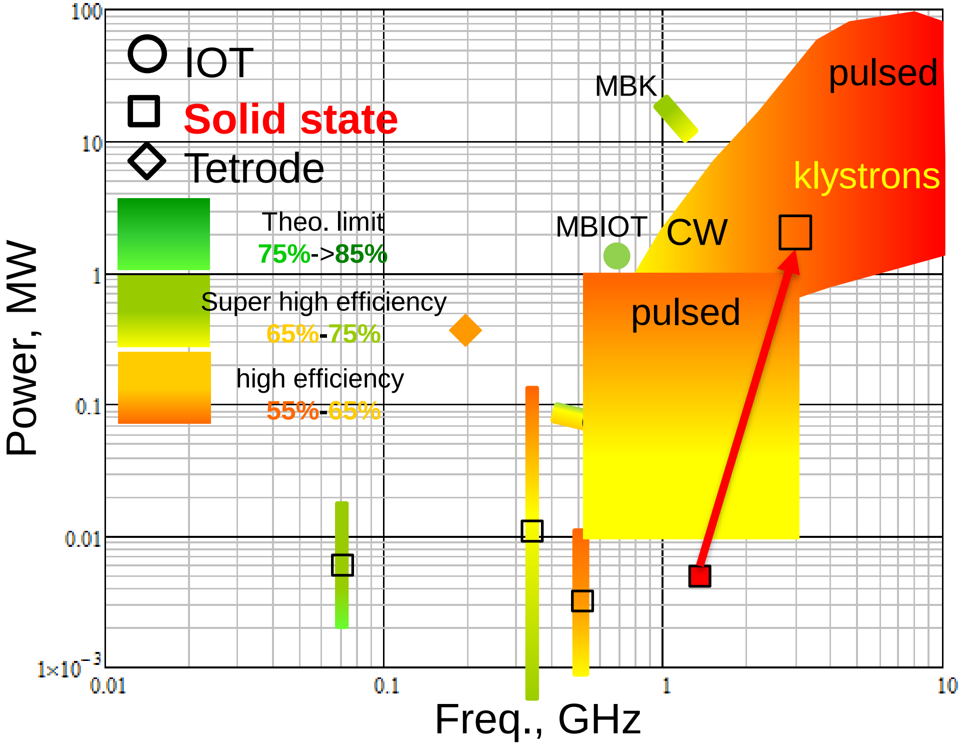
750Mhz功放板脉冲信号

输入反射 (dB)	栅压 (V)	静态增益 (dB)	静态电流 (mA)	供电电压 (V)	日期	13所氮化镓功放管，650M电路板改750MHz		换推动	功率衰减器后测试	
-30.2	-3		0.0075	52	2023.6.12	100us/100ms		未加耦合器偏		
信源输入 (dBm)	前级输出 (dBm)	板增益 (dB)	功放输出 (dBm)	功率 (W)	电流取样1 R01(mv)	电流取样2 R01(mv)	电源电流 (A)	二次 (dBc)	三次 (dBc)	效率 (%)
-24.82	38.08	12.04	50.13	103						
-22.09	40.08	12.98	53.06	202						
-21.66	41.36	13.45	54.8	302						
-20.74	42.36	13.7	56.06	403						
-20	43.14	13.87	57.02	503						
-19.38	43.82	13.99	57.81	604						
-18.86	44.38	14.08	58.47	701						
-18.36	44.91	14.16	59.05	803						
-17.92	45.37	14.19	59.57	905						
-17.52	45.8	14.25	60.05	1011				-37.2	-17.7	
-17.2	46.14	14.28	60.43	1103						
-16.86	46.51	14.31	60.82	1208						
-16.56	46.84	14.32	61.16	1308						
-16.26	47.16	14.34	61.5	1412						
-16	47.44	14.33	61.78	1505				-36.1	-15.7	
-15.74	47.72	14.33	62.05	1604						
-15.46	48	14.32	62.32	1707						
-15.24	48.24	14.32	62.56	1803						
-15	48.5	14.3	62.8	1905						
-14.78	48.73	14.28	63.01	2002				-36.1	-15.3	
-14.54	48.99	14.25	63.24	2108						
-14.26	49.27	14.16	63.43	2203						
-14.02	49.52	14.12	63.64	2310						
-13.8	49.74	14.07	63.81	2404						
-13.56	49.98	14.01	63.99	2507				-35.7	-14.5	
-13.32	50.23	13.93	64.16	2606						
-13.06	50.48	13.84	64.33	2708						
-12.78	50.74	13.74	64.48	2803						
-12.48	51.02	13.62	64.64	2909						
-12.18	51.3	13.51	64.82	3033						
-11.84	51.61	13.35	64.96	3133				-35.2	-14.4	



Single device 5kW

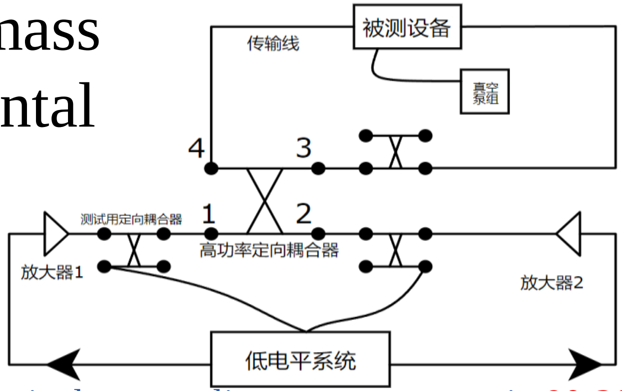
Plugin 25/50/100kW



Based on GaN transistors, the application frequency of solid-state power sources is increased to the ultra-high frequency (UHF) range of 300-3000MHz, and the peak power is increased by two orders of magnitude to the MW level.

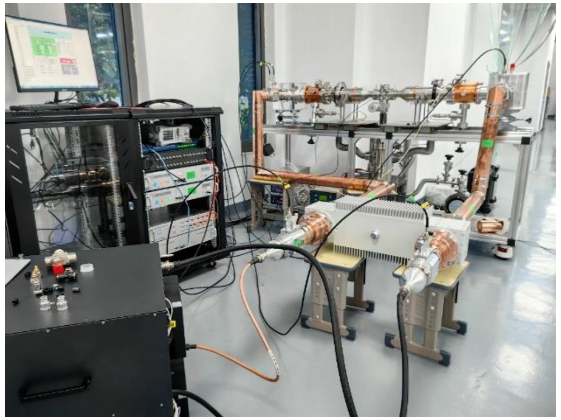
Fundamental Power Couplers

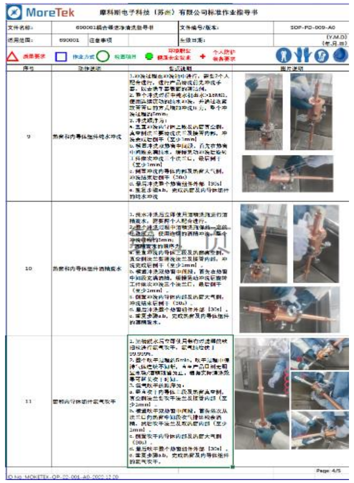
- Standard protocol and mass production for fundamental power couplers

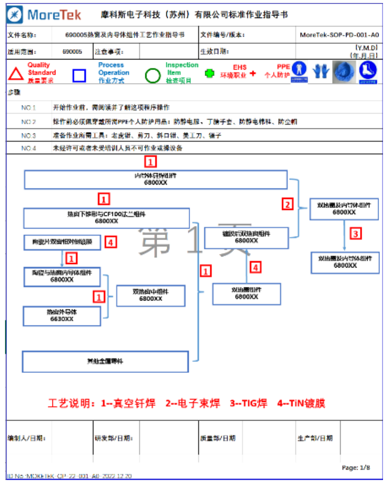


Equivalent traveling wave power gain 90-208

Harmonic conditioning







3. HIAF-iLinac

Brief introduction of HIAF project

- Approved in Dec. 2015, Ground broke in August 2018, Officially started in July 2021
- Leading institute: IMP
- Budget: ~3 B CNY (Gov. 1.5B + Local Gov. 1.2 B)
- Location: Huizhou, Guangdong Prov.

Brief introduction of HIAF project

Scientific goals:

- Nuclear Physics

  Nuclear Structure and Nuclear Astrophysics

  Nuclear matter and hadron physics

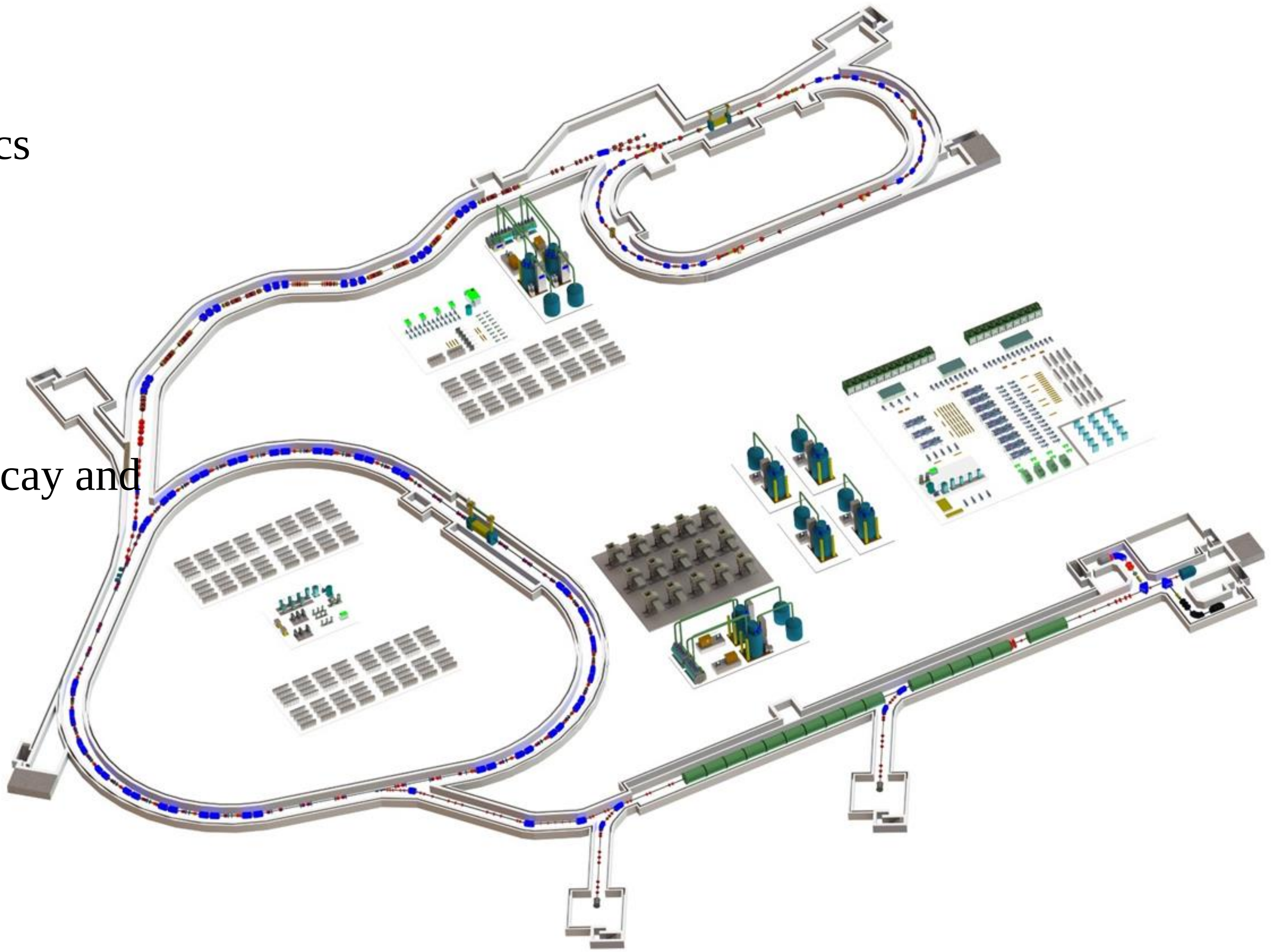
- Fundamental Physics

  Ultra Strong Field QED

  High Energy Density Matter

  High brightness frontier: μ, k-rare decay and nucleon interactions, CP, ν

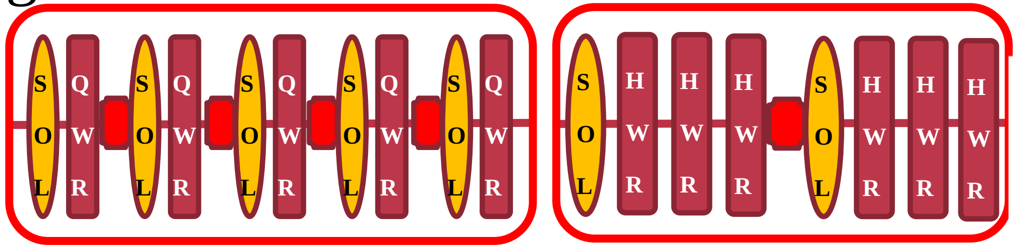
  Electron-ion Colliding



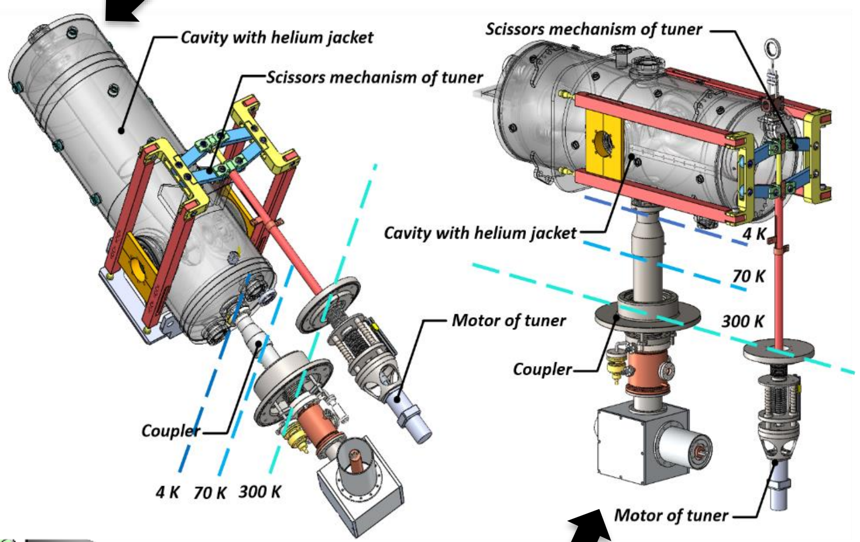
HIAF iLinac

Cavities: QWR007 & HWR015

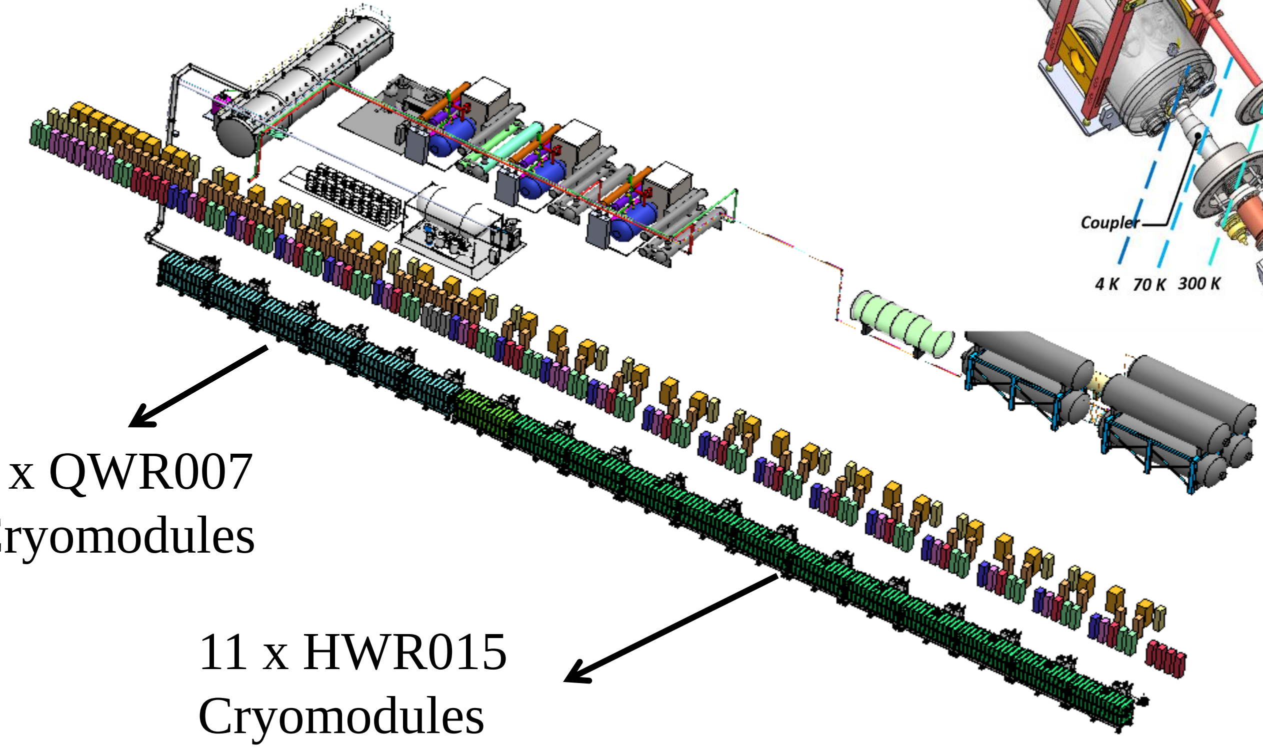
Energy goal: 17.2MeV/u for U^{35+}



QWR007 with ancillary components



HWR015 with ancillary components



6 x QWR007
Cryomodules

11 x HWR015
Cryomodules

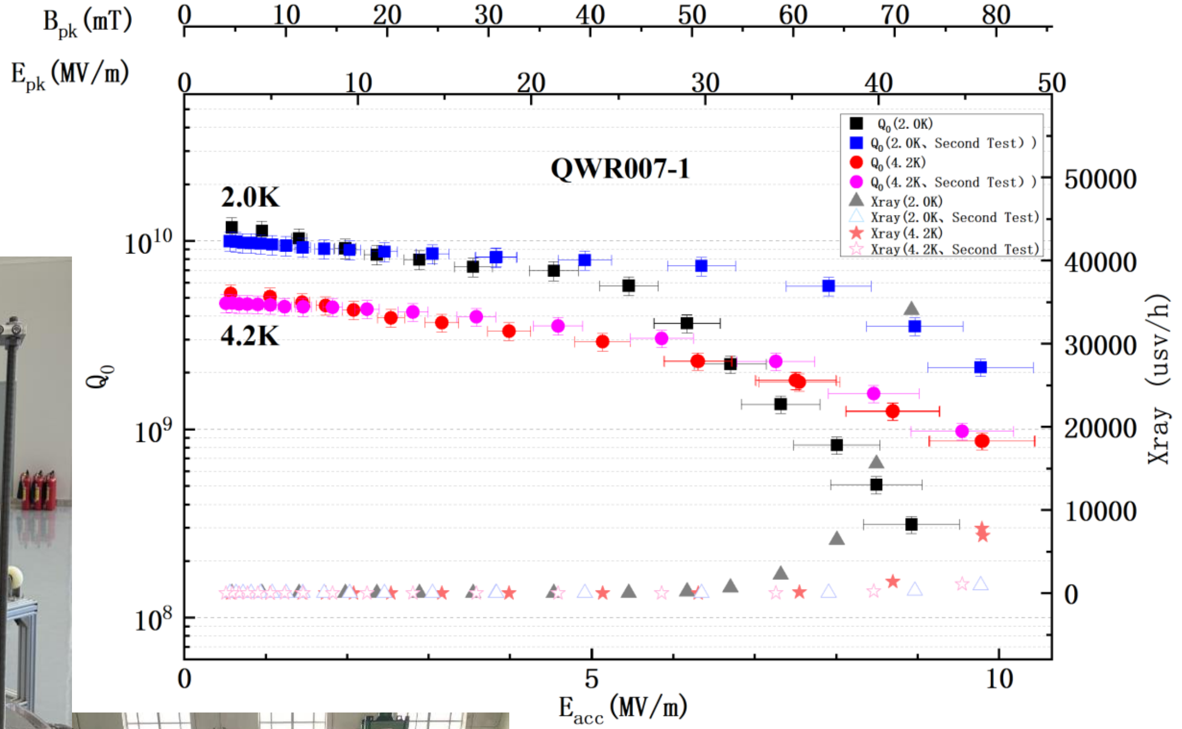
Cavity Fabrication and Test

QWR007:
Completed 4 cavities
First cavity tested twice with light-BCP re-processing.

HIAF Specification @2K: E_{pk}>28MV/m, Q_0>1.5E9 (@ 28MV/m), No FE within test range.

Actual results:
E_{pk}>**45**MV/m,
Q_0>**6.0**E9 (@ 28MV/m), Rs<5nΩ,
P_{diss}<0.8W

Passed

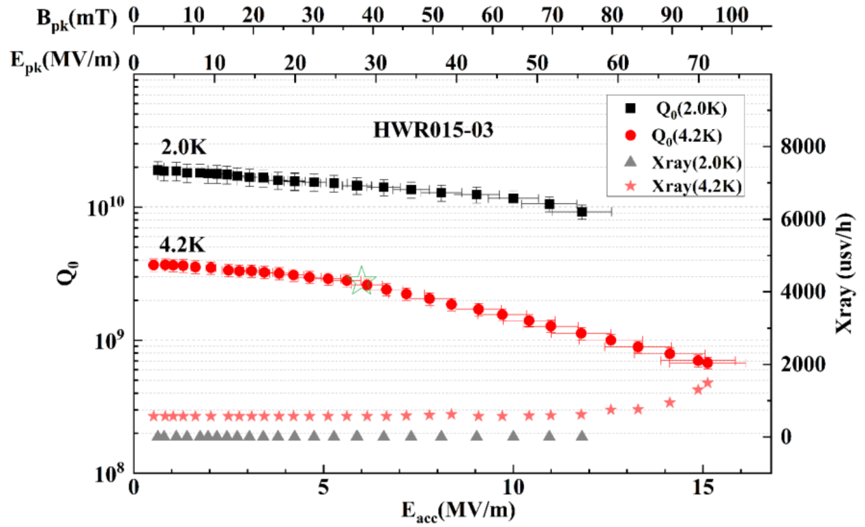


HIAF iLinac

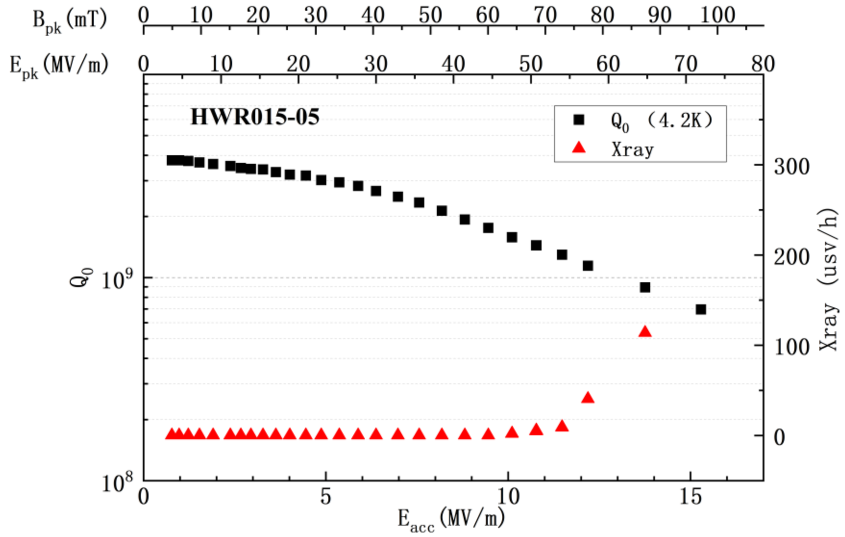
Cavity Fabrication and Test

HWR015:
Completed 6 bare cavities and 1 jacketed cavity
2 cav. tested @ 4.2K,
1 cav. tested @ 2K.
Both E_{pk}>70MV/m
R_{res} < 6nΩ, meet HIAF specification:
Q_0=2.86E9 @2K

HWR015-3



HWR015-5



Traditional Cryomodule for Bulk Nb Cavities

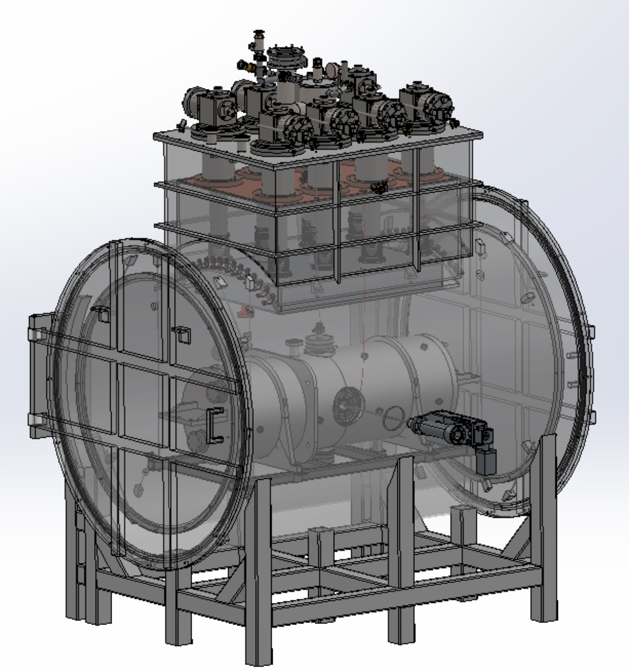
- Vacuum chambers, thermal shields, coldmass frames, G10 posts, and multi-channel pipelines have been finished for both QWR007 and HWR015 cryomodules.
- Both types have undertaken leak tests and thermal shock tests.
- Cryomodules are ready to be shipped to project sites as soon as the test bunker is ready.

Cavity Fabrication and Test

Single cavity dewar for VT:

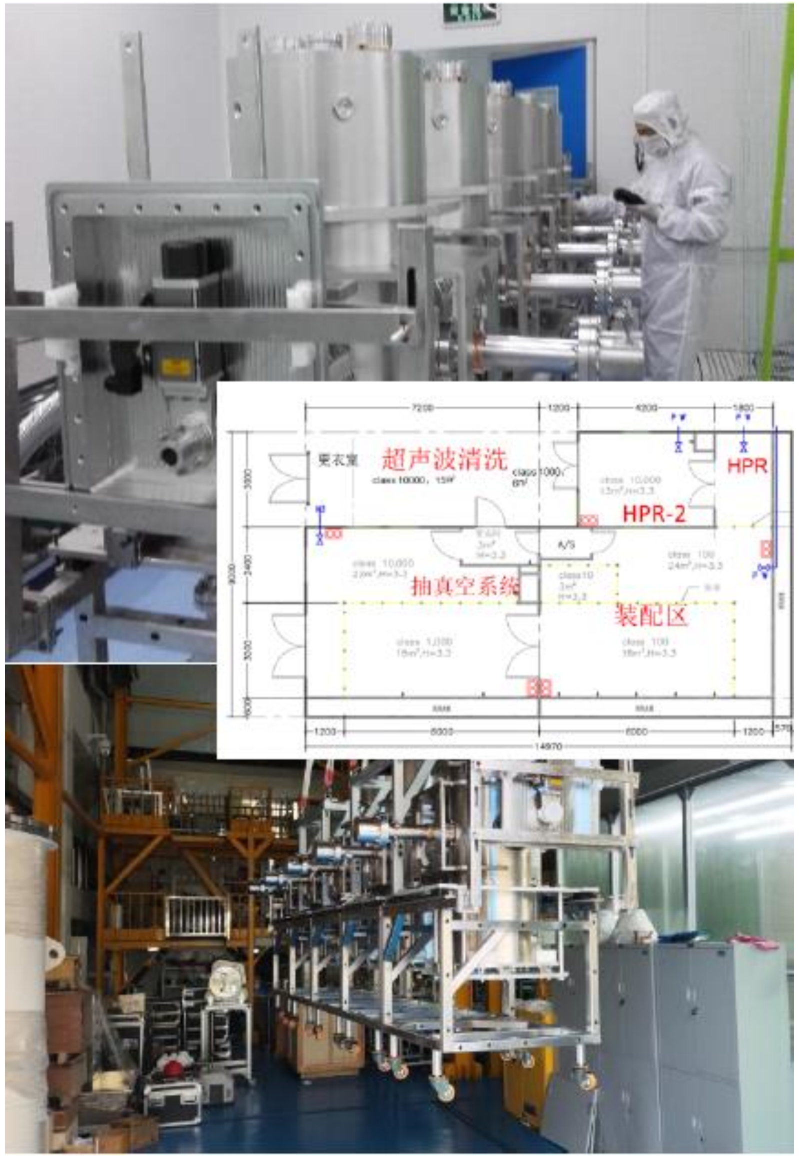
1. He-filled dewar @ Lanzhou
   8W static heat load;
   1 week installation time for each cavity;
   400L LHe capacity;
   1 cavity successfully tested.

2. Cryocooler-driven dewar @ Huizhou
   Similar static heat load and installation time;
   8 cryocooler provided enough test capacity for low beta cavities;
   Almost no LHe consumption;
   Engineering design finished.



4. infrastructure

Lanzhou campus

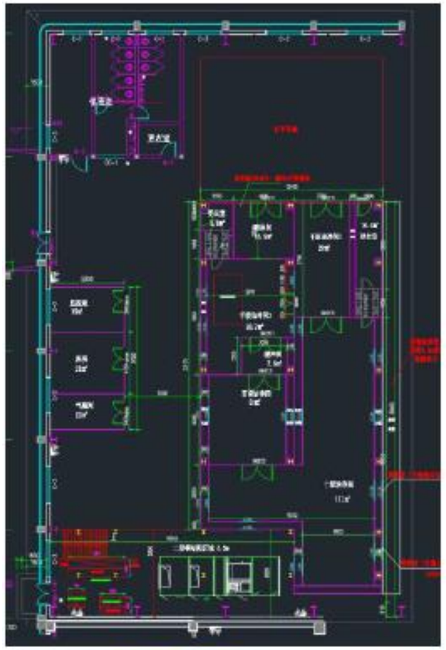


130㎡, Class-5, 1 robot, maximum assembly capacity: 1 string per 6 weeks.

Assembled more than 10 strings fro CAFe and CAFe2.

Now mainly works for research cavities.

Lanzhou new area campus

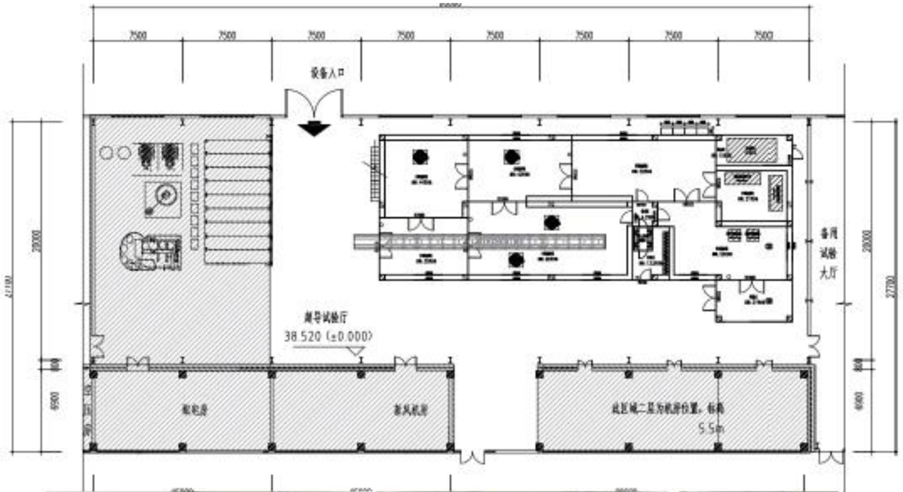


310㎡, Class-4, 3 robot, maximum assembly capacity: 1 string per 4 weeks.

Assembling strings for IP-SAFE.

Now under intense assembly jobs.

Huizhou HQ campus



445㎡, Class-4, 4 robot, maximum assembly capacity: 1 string per 4 weeks.

Assembling strings for CiADS and HIAF.

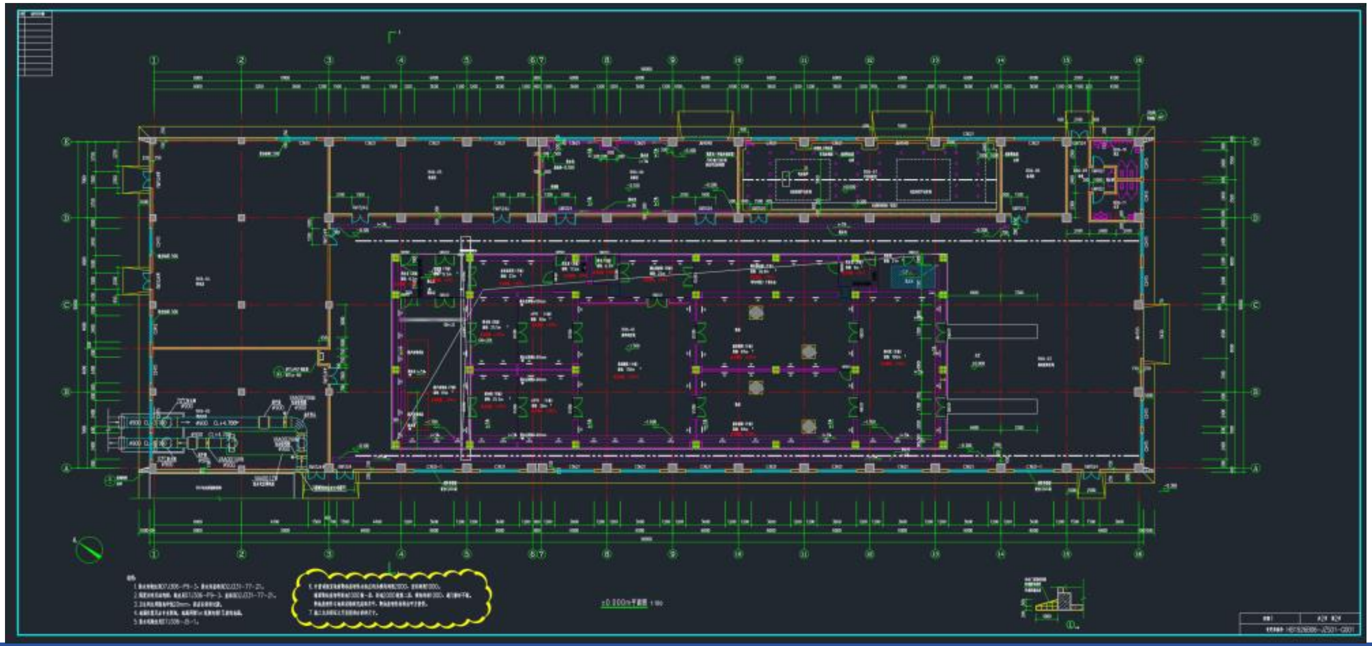
Now under intense assembly jobs.

CiADS campus

900㎡, Class-4, 9 robot, maximum assembly capacity: 2 string per 4 weeks. Commissioned this month.

Assembling strings for CiADS, HIAF, and potnetial upgards.

Now under intense assembly jobs.

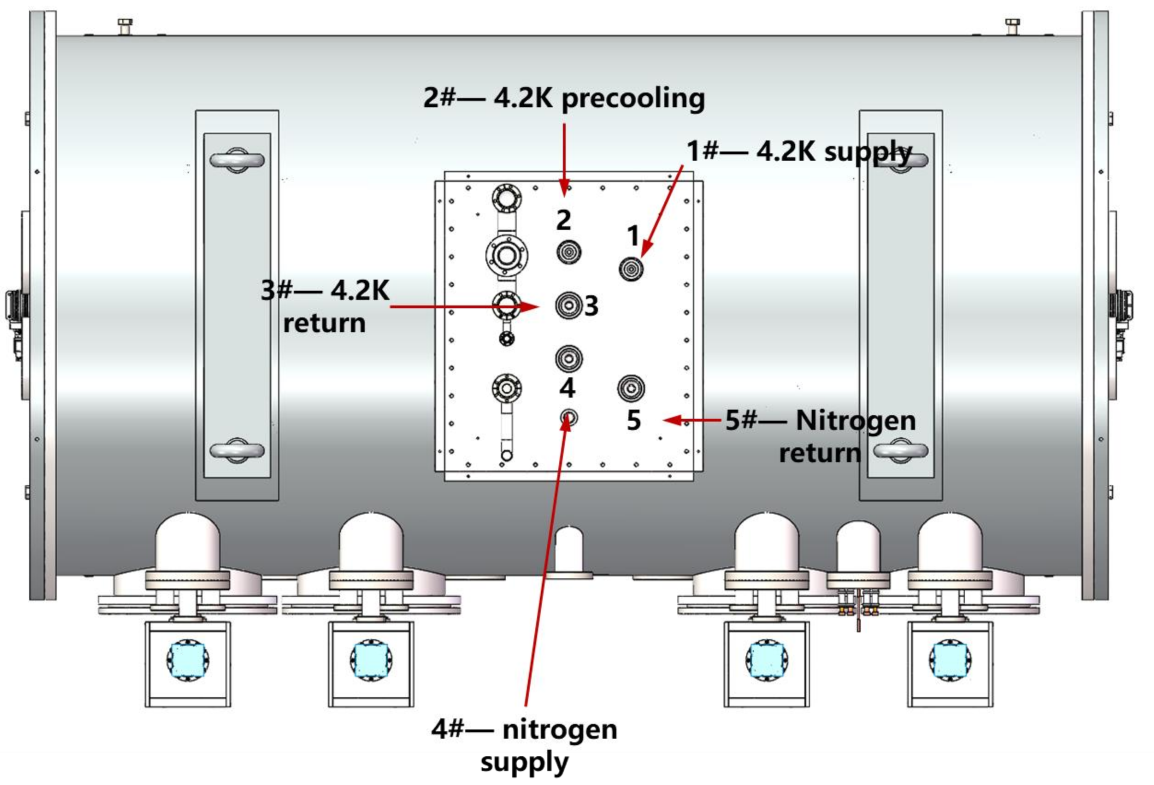


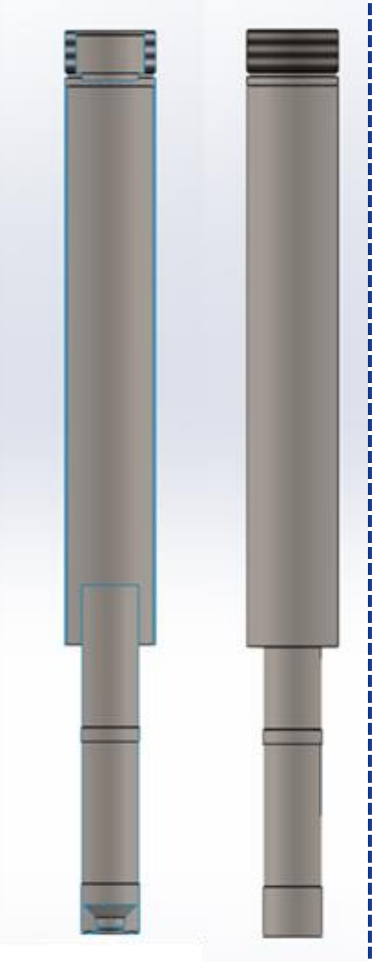
Спасибо за внимание
Thank you for your attention

- **Backup slides**

Cooling System — Multi transfer lines interface

Position of each bayonet



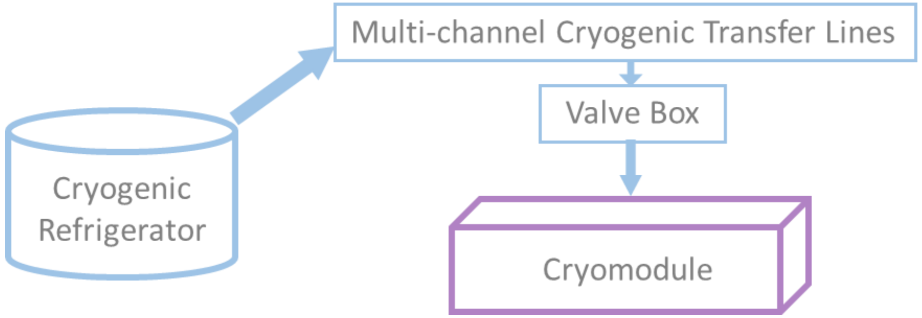


Name	Bayonet
1# 4.2K supply	DN10
2# Nitrogen supply	DN10
3# 4.2K return	DN15
4# 4.2K precooling	DN15
5# Nitrogen return	DN15

Cooling scheme

Online

- Select the appropriate placement for cryomodule.
- Design layout of pipelines from cryogenic plant to cryomodule.
- Install the valve box before the cryomodule to control the pressure, mass flow rate ,etc.



Not Online : Use LHe and LN2 dewars to cool down the cryomodule and its thermal shield.

Easier



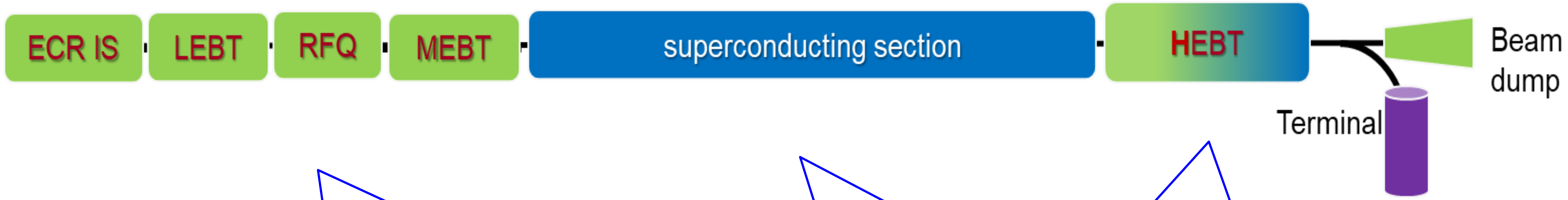


set pressure of safety

Operation pressure and set pressure of vessel of cavity and thermal shield（already installed and cannot change）

Name	Operation pressure	Set pressure of safety valve	Set pressure of bursting discs
Vessel of cavity (4K)	1.05 bara	2.2 bara	2.5 bara
Thermal shield	3.5 bara	5.0 bara	5.5 bara

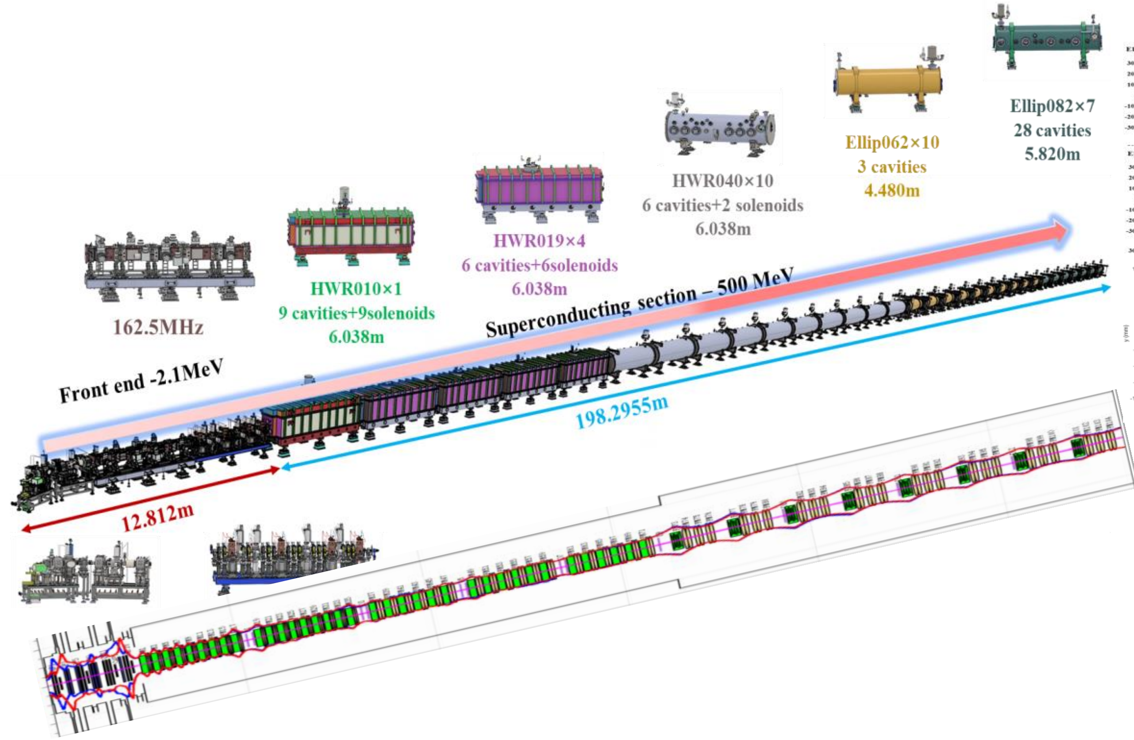
Direction 1：Beam physics design

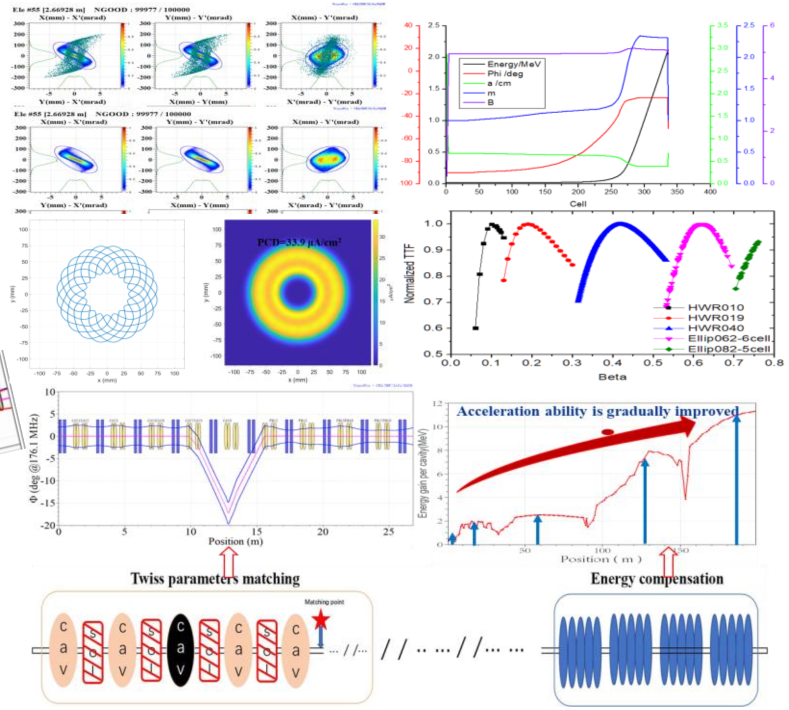


- High transmission efficiency
- Good beam matching
- High beam quality

- High acceleration efficiency
- Low beam loss
- Fault compensation

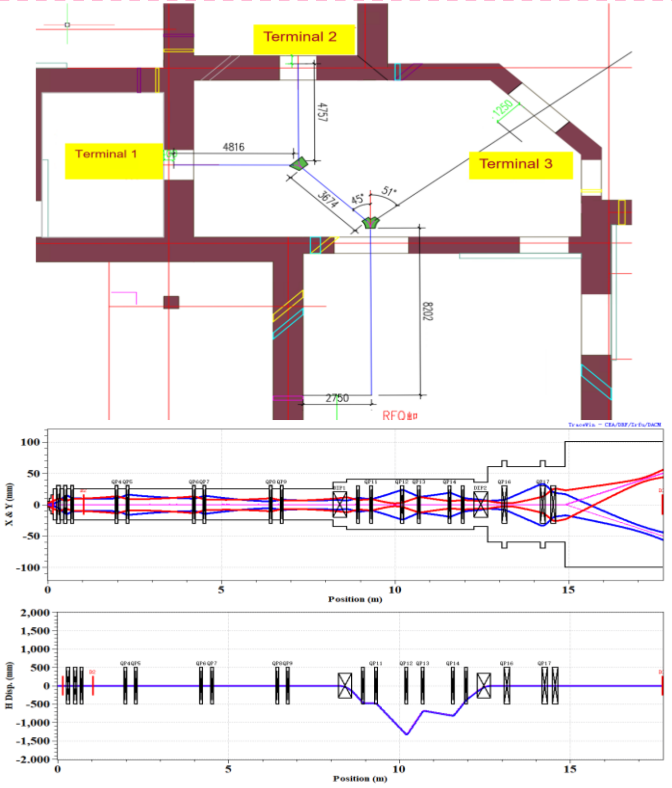
- High transmission efficiency
- Good beam matching
- High beam quality



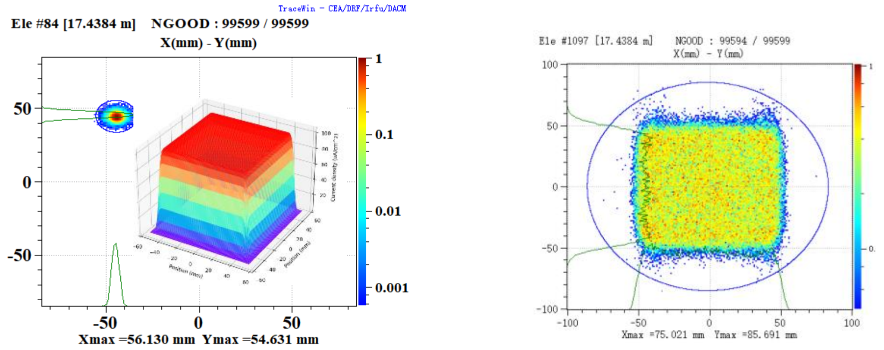


Direction2: Beam manipulation and shaping

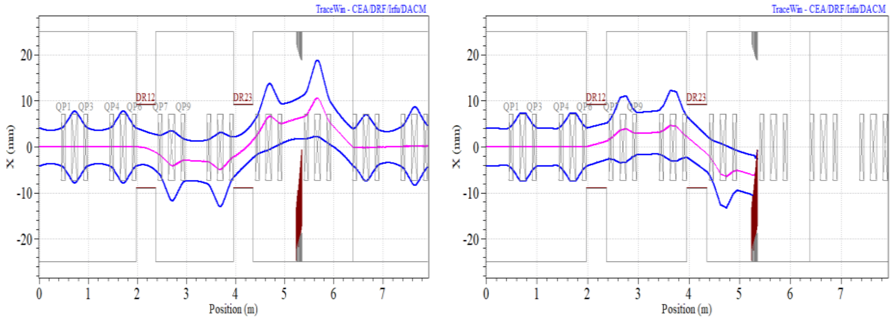
Way: Beam transmission line beam optical design
Objective: To achieve the stated target of the accelerator beam and target requirements matching
Approach: The beam size, beam density, beam intensity, time structure and space pattern manipulation



Multi-terminal beam matching optical design



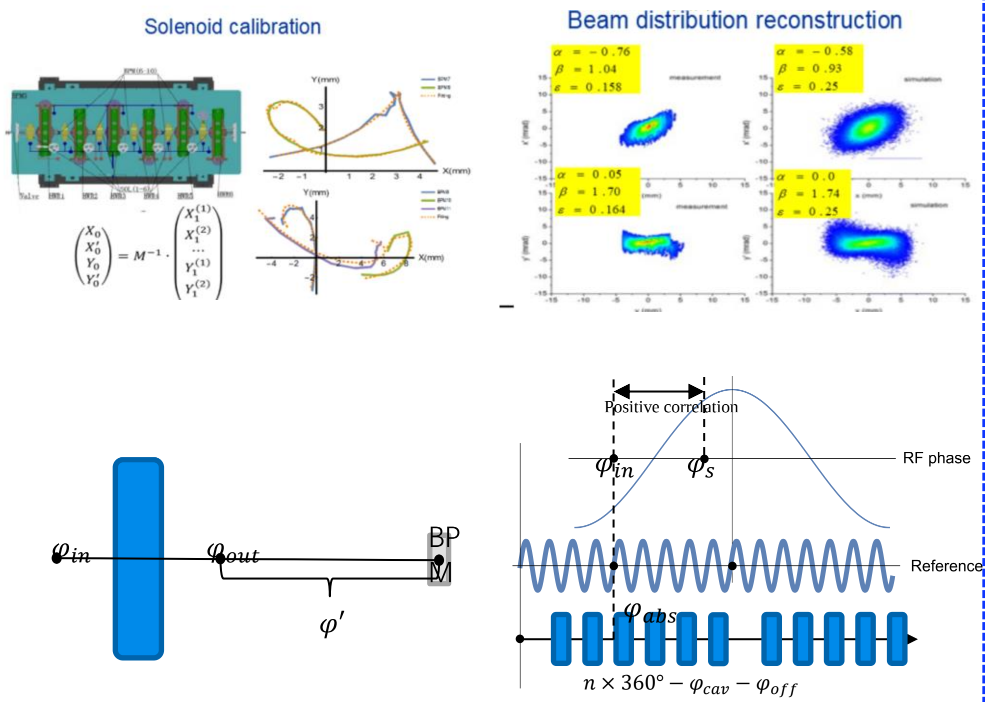
High power beam uniformazation (beam density and distribution control)



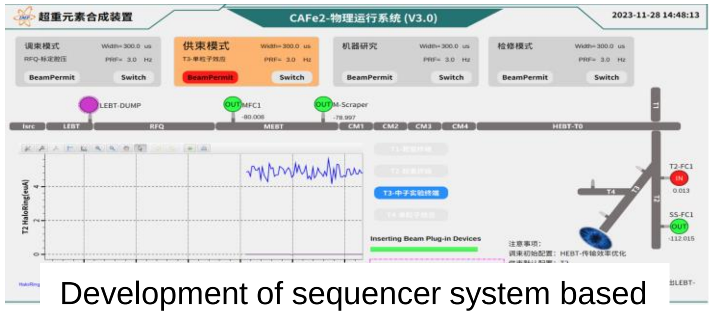
bunch-by-bunch selection（time structure control）

Direction3:Accelerator Commissioning and operation technology

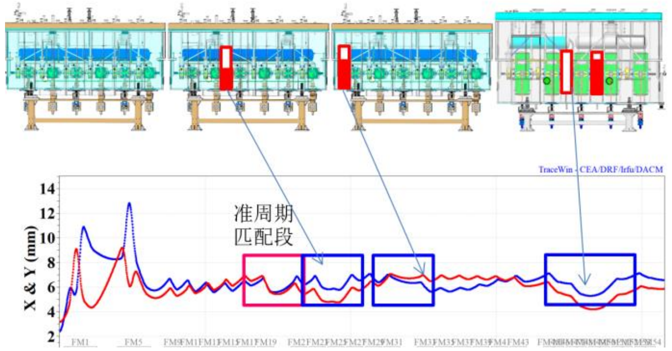
Position: accelerator commissioning personnel;
Objective: Accelerate the beam to the target energy with low or no losses, and provide a stable beam for end applications.
Approach: Accelerator physics + control technology + machine research + big data analysis + AI-assisted technology -> intelligent beam conmissioning



Phase scan and Cavity calibration



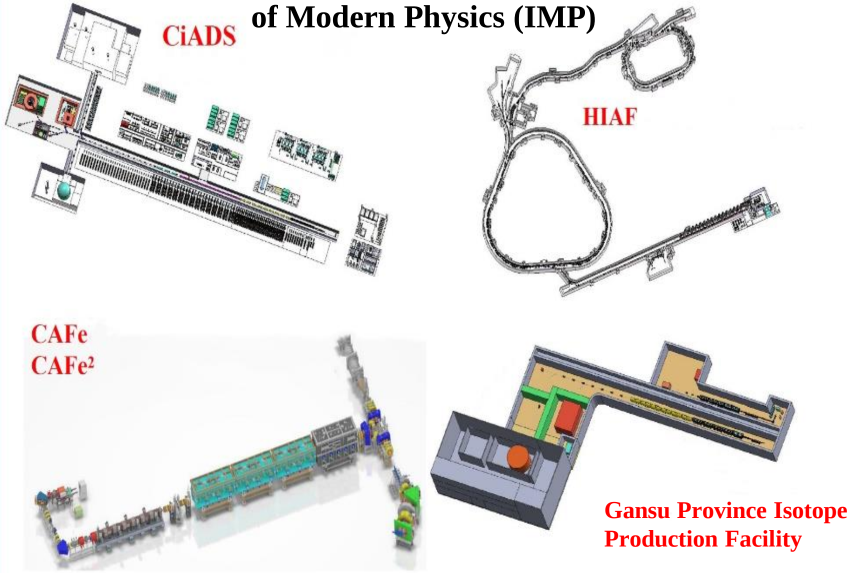
Development of sequencer system based on beam tuning technology



Failure compensation and beam halo control

Direction 4: Accelerator simulation software

Major Accelerator Facilities Constructed at the Institute of Modern Physics (IMP)

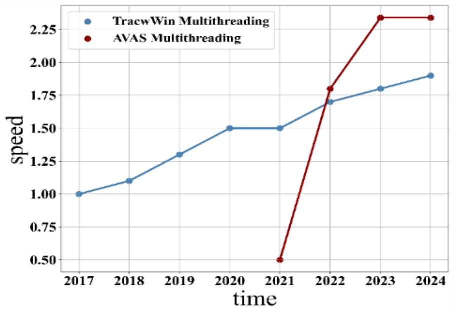


Advanced virtual accelerator software (AVAS): a design, simulation, and analysis platform for high-power linear accelerators

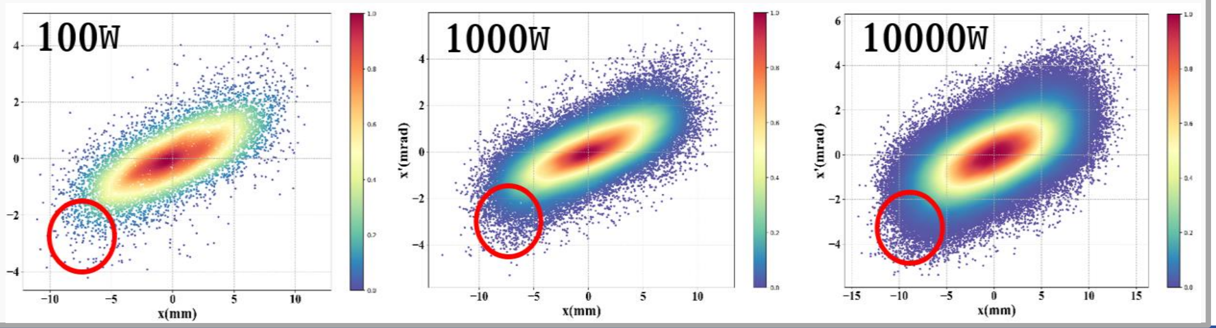
Simulation of ADS Injector II RFQ at 0 mA Beam Current

AVAS is a simulation platform specifically developed for high-power accelerators. It supports parallel computing on a scale of over 100 million and is significantly faster than similar software.

Speed comparison between AVAS and TraceWin



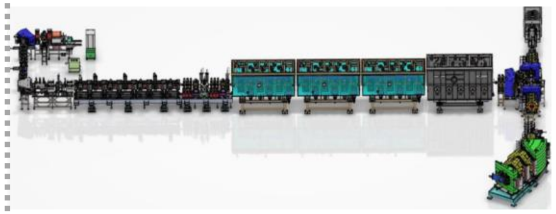
Numerical simulation results of AVAS under different simulation scales



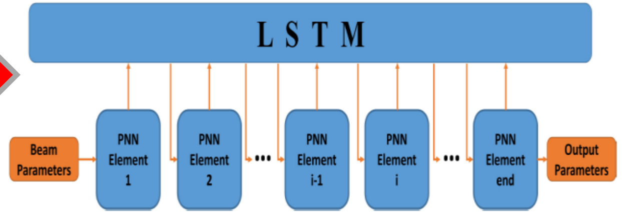
Direction 5: AI-Based Ultra-Fast Dynamics Simulation

Objective: surrogate models based on neural network to achieve ultra high speed beam dynamics simulations

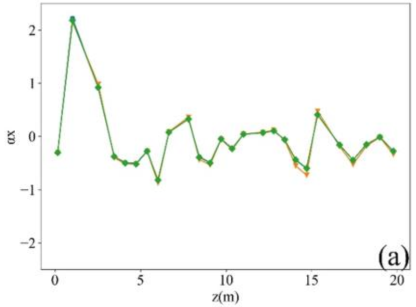
CAFe2



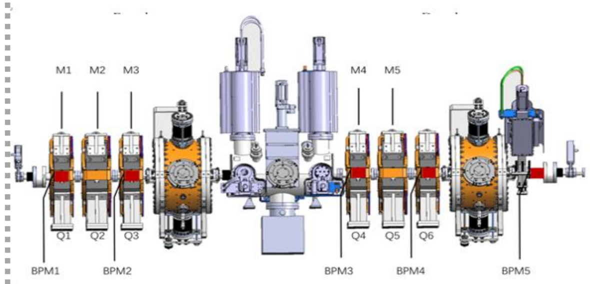
PNN-LSTM Dual Nested Neural Networks



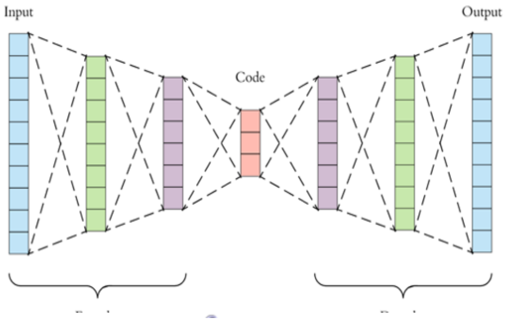
Model accuracy reaches 98%
Simulation time reduced from 165s to 0.2s.



CAFe2 MEBT

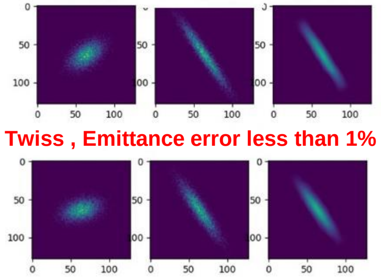


Encoder-Decoder Architecture



Comparison of surrogate Model with AVAS: Simulation time reduced from 7s to 9ms.

Entrance Phase Space　AVAS Calculation　Model Prediction



Twiss , Emittance error less than 1%

Using a dual network with PNN-LSTM nested structure to realize start-to-end accelerator surrogate model, International Journal of Modern Physics A

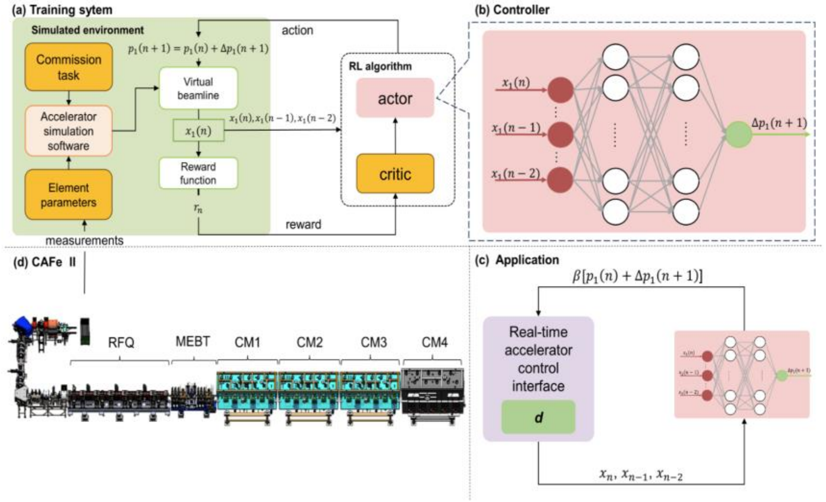
Surrogate model of particle accelerators using encoder-decoder neural networks with physical regularization. International Journal of Modern Physics A

Direction 6: Accelerator Automatic Operation System Based on Reinforcement Learning

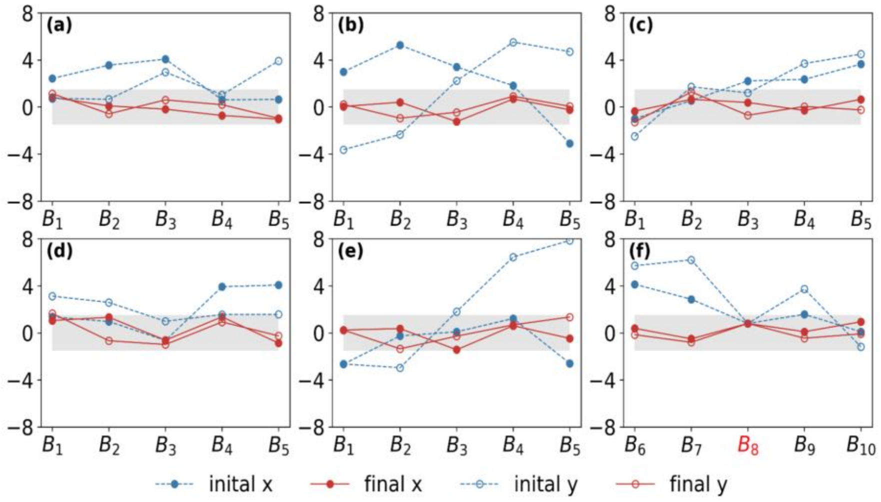
Objective: **Implementing 'autonomous driving' in accelerator operation and commissioning process based on reinforcement learning technology**

Automatic Beam alignment on CAFe2

Using AVAS to build a virtual accelerator of CAFe2, Agent is training on AVAS, but it can be directly applied on CAFe2



Online adaptive controller automatically corrects the CAFe2 beam centroid to within 1mm within 3minutes



Orbit correction based on improved reinforcement learning algorithm, PHYSICAL REVIEW ACCELERATORS AND BEAMS
Machine Learning for Online Control of Particle Accelerators, Science China Physics Mechanics and Astronomy

- **High dimensional phase space distribution required to predict evolution of high intensity beams**
  - 2D phase space distributions not enough
- **Tomography: reconstruct high dimensional distribution from low dimensional projections**

Maximum entropy tomography of 4D phase space distribution from 2D measurements

Constraints (from 2D measurements) $$G_j[\rho] = g_j(u_j, u'_j) - \iint \rho\left(\vec{x}\left(\vec{u}_j\right)\right) dv_j dv'_j = 0$$

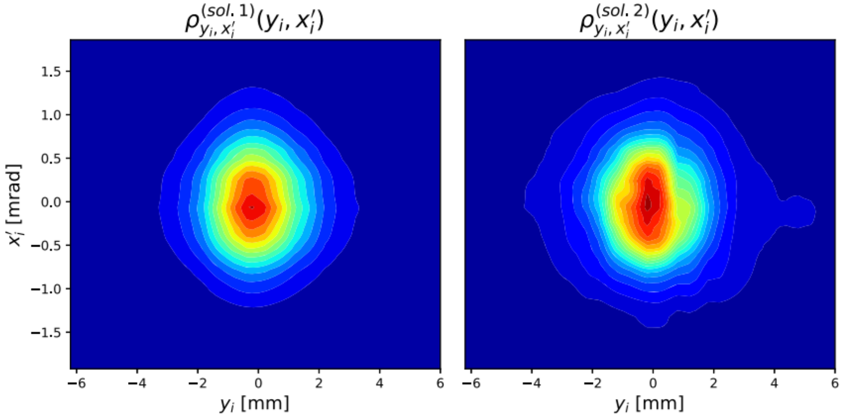
Maximum entropy distribution $$\rho = C_1 \exp\left(\sum_{j=1}^{n} \lambda_j(u_j, u'_j) - 1\right) = C_2 \prod_{j=1}^{n} h_j(u_j, u'_j)$$

Iterative solution to nonlinear equations $$h_k^{(m+1)}(u_k, u'_k) = \frac{g_k(u_k, u'_k)}{\tilde{g}_k^{(m+1)}(u_k, u'_k)}$$

$$\tilde{g}_k^{(m+1)}(u_k, u'_k) = \iint C_2 \prod_{j=1}^{k-1} h_j^{(m+1)}(u_j, u'_j) \prod_{j=k+1}^{n} h_j^{(m)}(u_j, u'_j) dv_k dv'_k$$

x-x' and y-y' measurements only

4D tomography



- **Tomography uncovers more information**
  - detailed structure of the distribution