Recent Status of SRF Projects for Hadron Accelerators in China

Yuan He,
Chief Engineer of CiADS
on behalf of CiADS, HIAF, CSNS-II and IP-SAFE teams

Outlines

Rapid Advancing of Hadron Machine @ China

Ongoing Projects

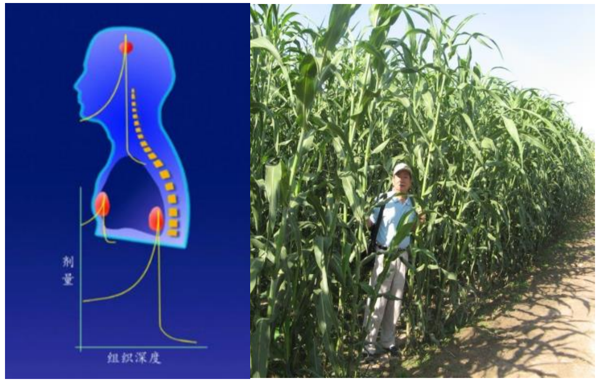
- CAFe2
- CiADS
- HIAF
- CSNS-II
- IP-SAFE

Potential Upgrade Projects

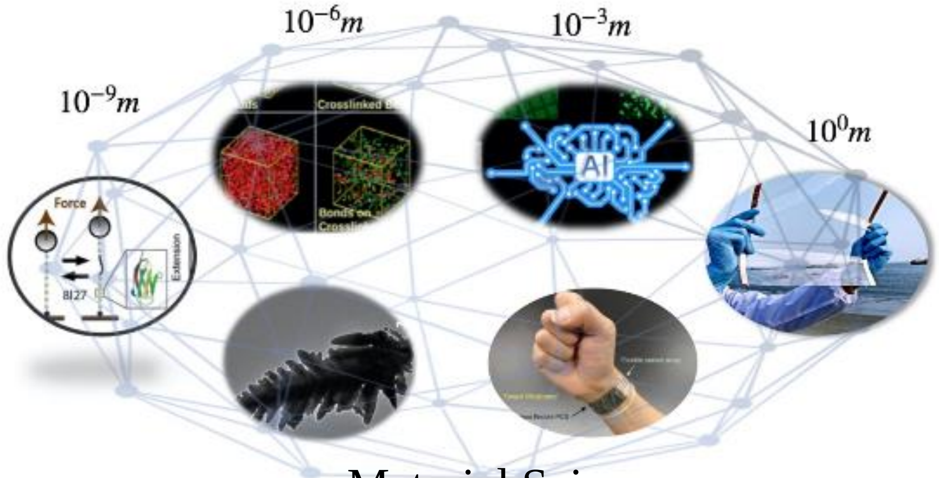
- CiADS Beam Intensity
- HIAF SCL2 with stripping foil

Rapid Advancing of Hadron Machine

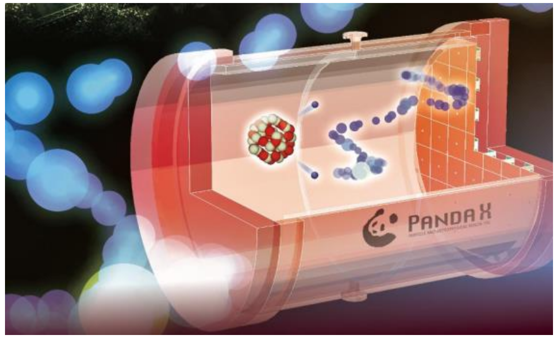
Superconductors



Medical and Biological Applications

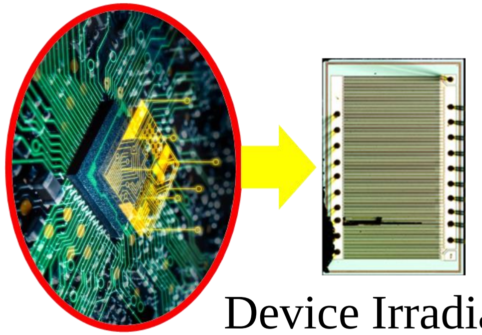


Material Science

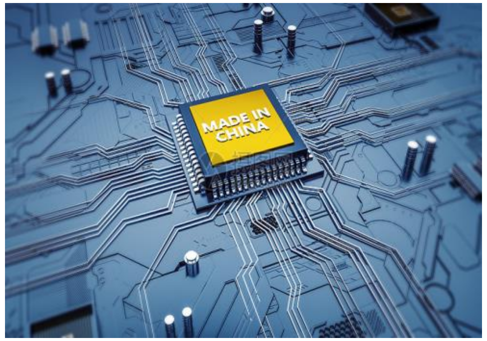


Dark Energy Detector

Heavy Ions Affect Human

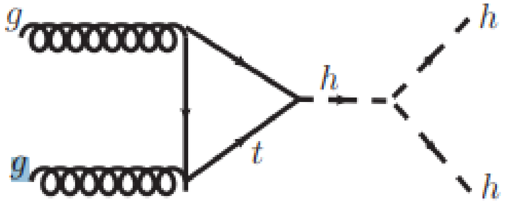


Device Irradiation Tests

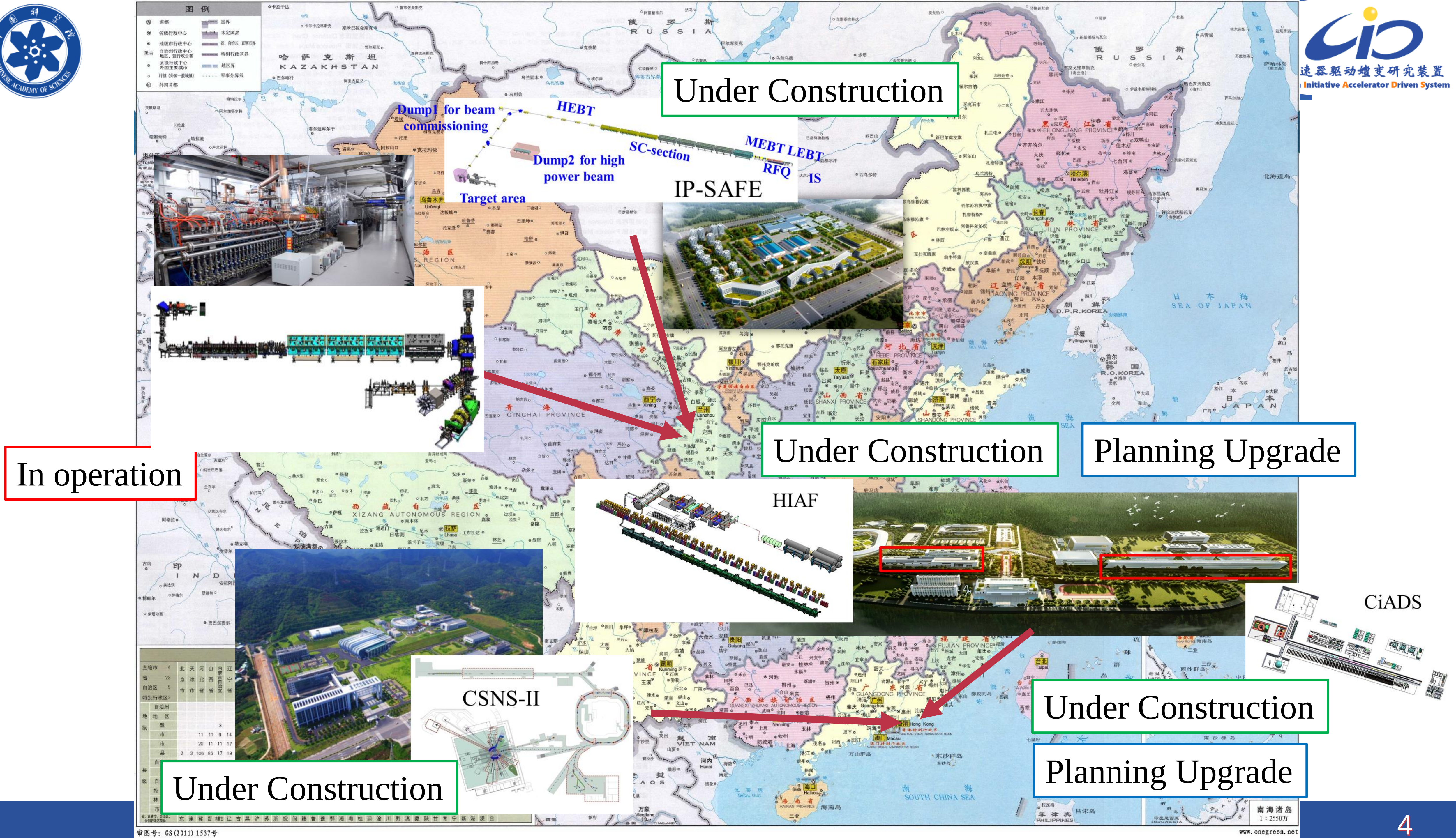


Ion Implantation

Nuclear Energy



New Physics


Under Construction
Dump1 for beam commissioning
HEBT
SC-section
MEBT LEBT
RFQ
IS
Dump2 for high power beam
Target area
IP-SAFE
In operation
Under Construction
Planning Upgrade
HIAF
CiADS
CSNS-II
Under Construction
Under Construction
Planning Upgrade
先进加速器驱动嬗变研究装置
Initiative Accelerator Driven System

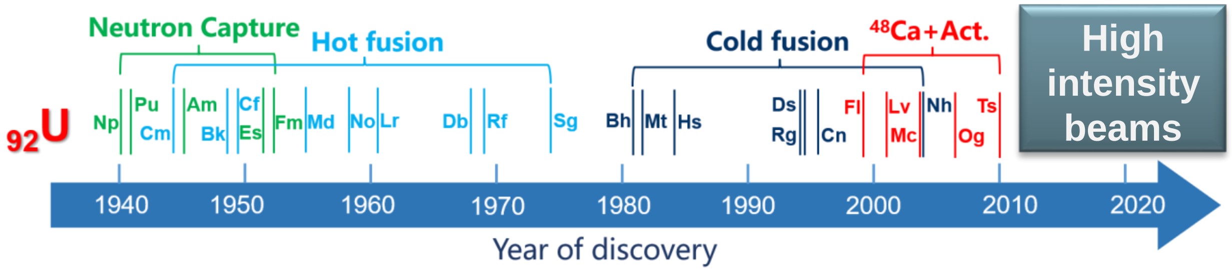
1. CAFe2

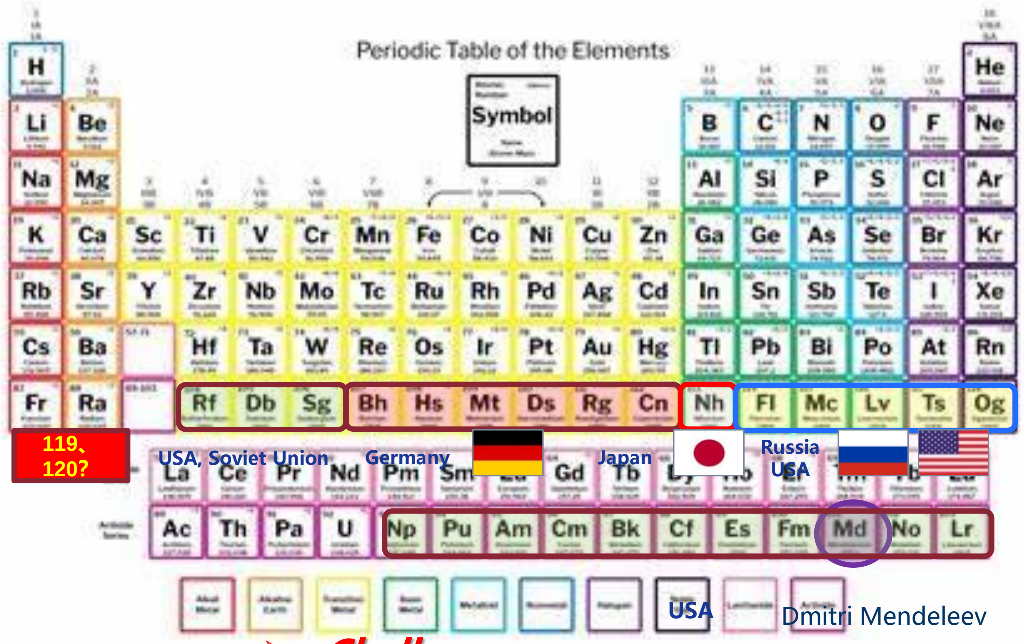
CAFe2 Objects-Superheavy Elements (Z>103)

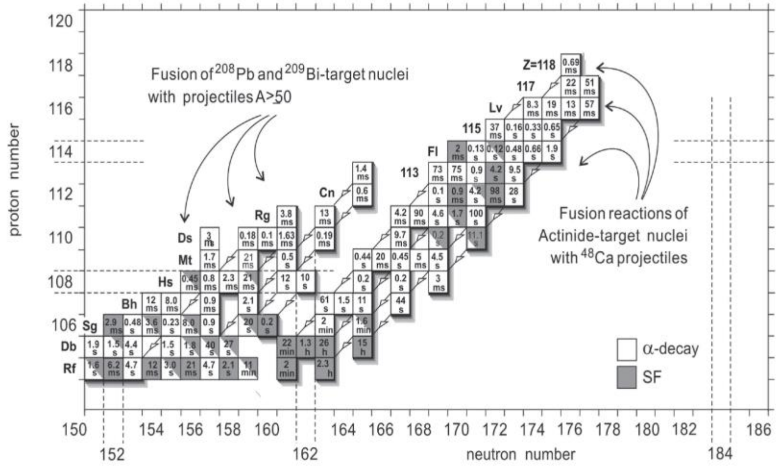
加速器驱动嬗变研究装置 China initiative Accelerator Driven System

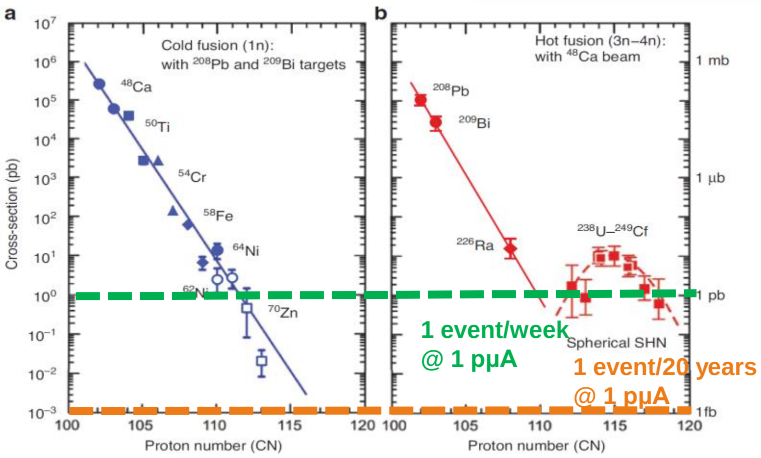
Top science questions：

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









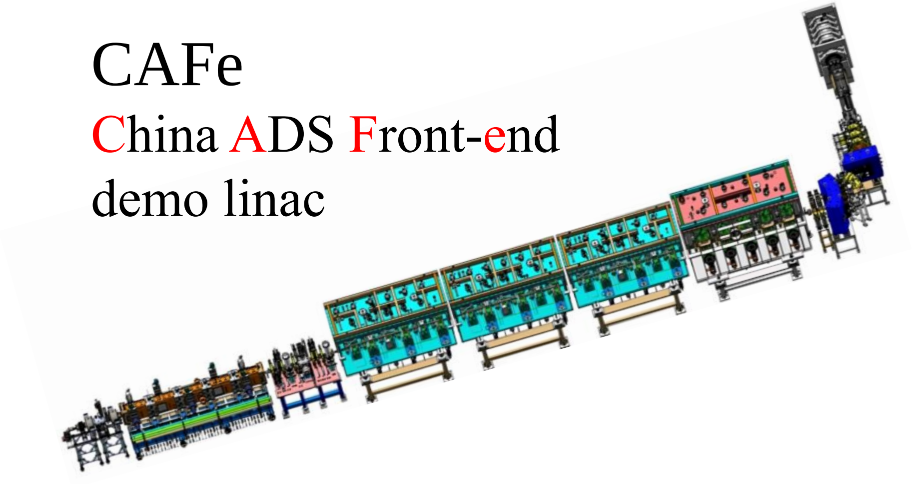
S. Hofmann, in *Radiochimica Acta* **107**, 879 (2019).

➢ ***Challenges:***

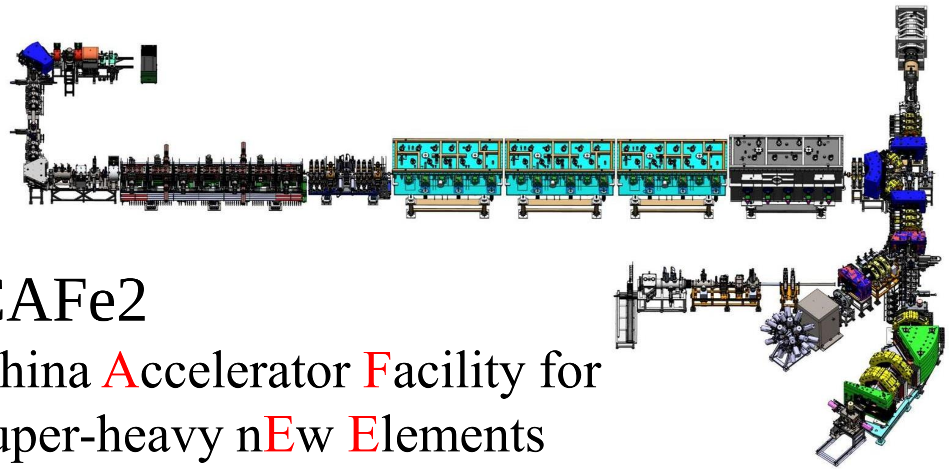
- **High beam intensity with Ca~Zn ions (5~10 pμA)**
- **Long beam time (a few months or years expt.)**
- **Actinide target material (U, Am, Cm, Cf …)**
- **Rotating target withstanding high power beams**
- **High efficiency separator**
- **Atom-at-a-time detection and DAQ**

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	



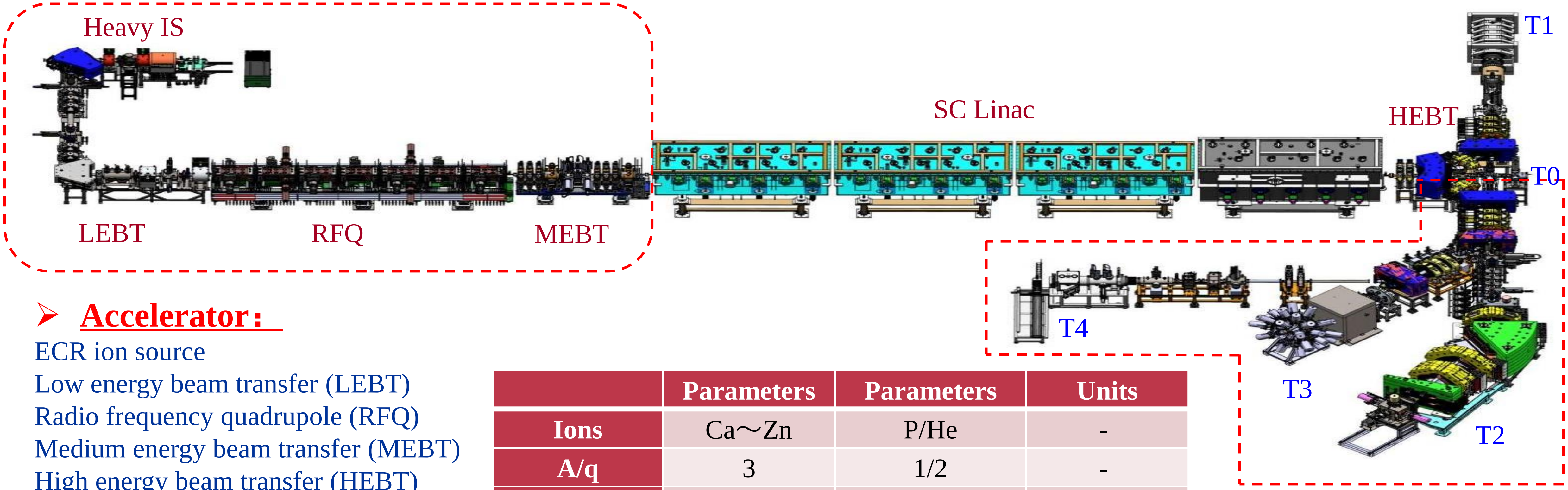
CAFe2
China Accelerator Facility for super-heavy nEw Elements

Commissioning campaigns

1. **Mar. 2021, CAFe achieved nominal specification, CW beam**
   - **20 MeV, 10 mA, 200kW, Proton;**
   - **17.3 MeV, 7.2 mA, 127kW, 108 h; and 10 mA, 174 kW, 12 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:

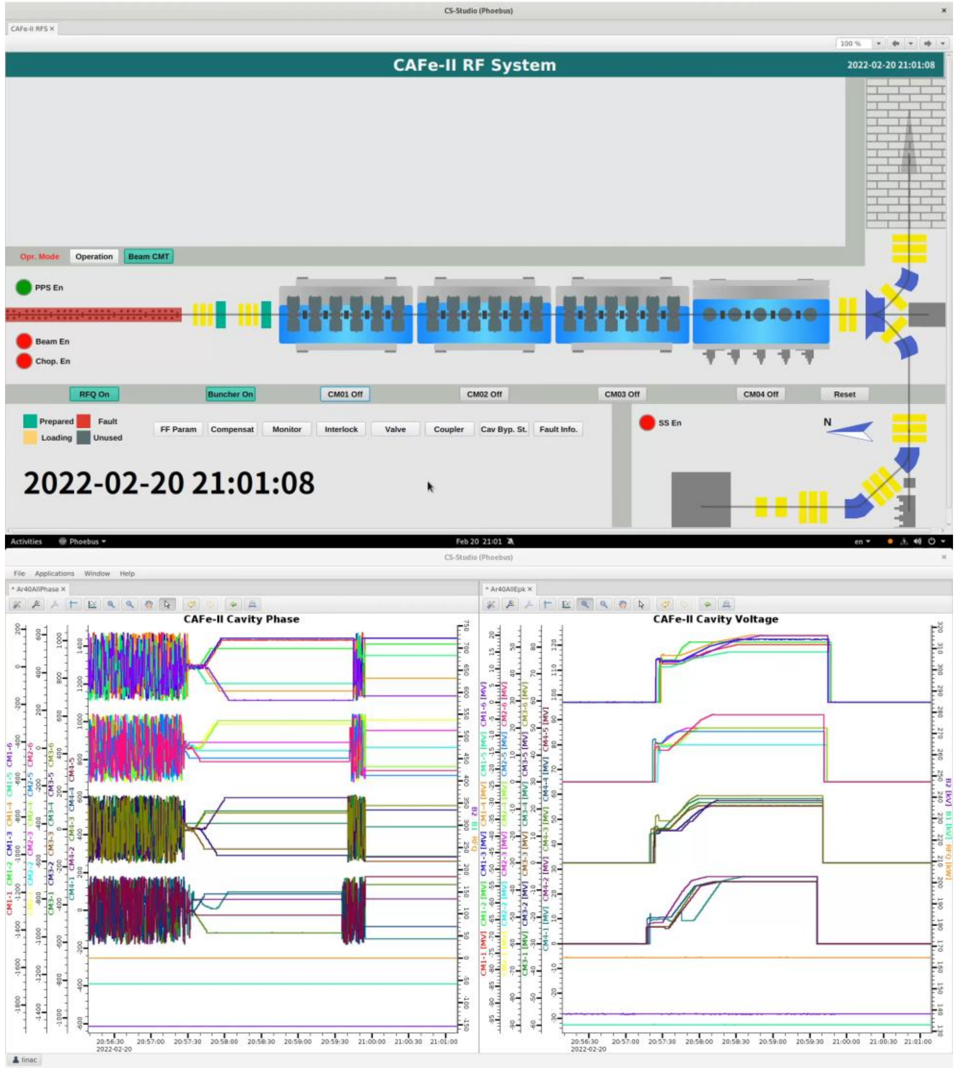
T0: Beam commissioning
T1: High power beam dump
T2: Spectrometer for Heavy Atoms and Nuclear Structure (SHANS2)
T3: Low power irradiation
T4: Proton Radiation Effects (PRE)

	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	-

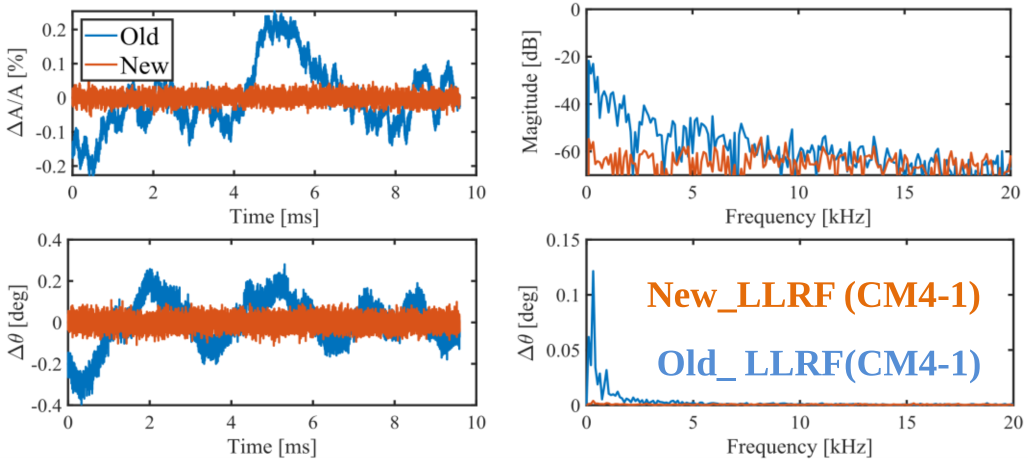
Goals：

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

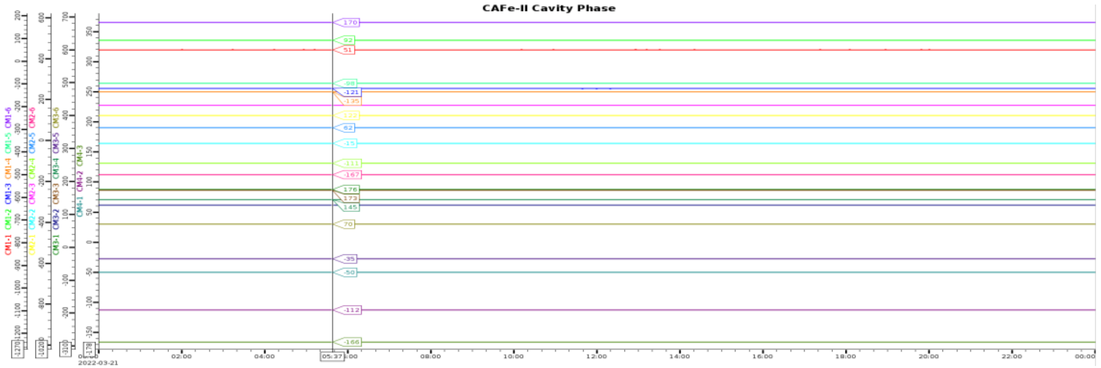
加速器驱动嬗变研究装置
China Initiative Accelerator Driven System



Cavity auto turn-on and recovery



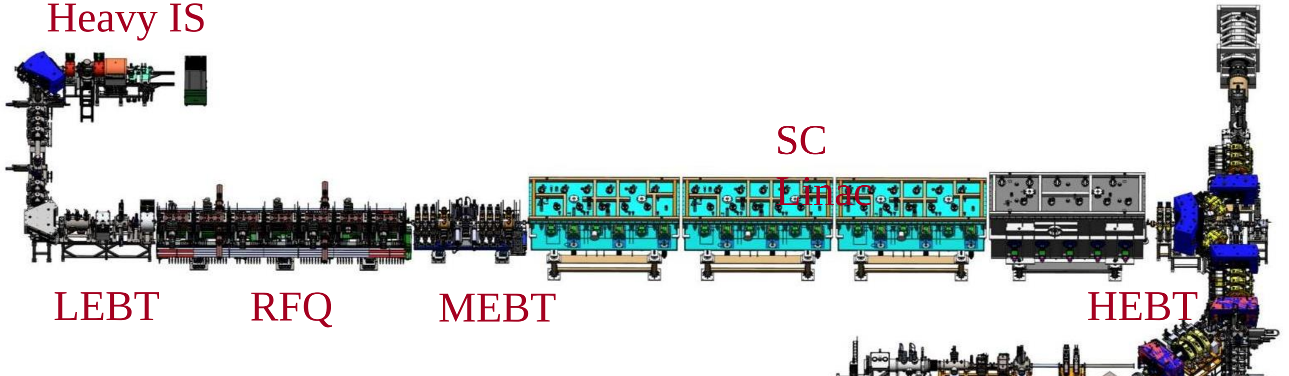
Amplitude and phase errors:(0.02%， 0.04 deg）@10mA



CAFE2 23 SC cavities in close loop（24 hours）

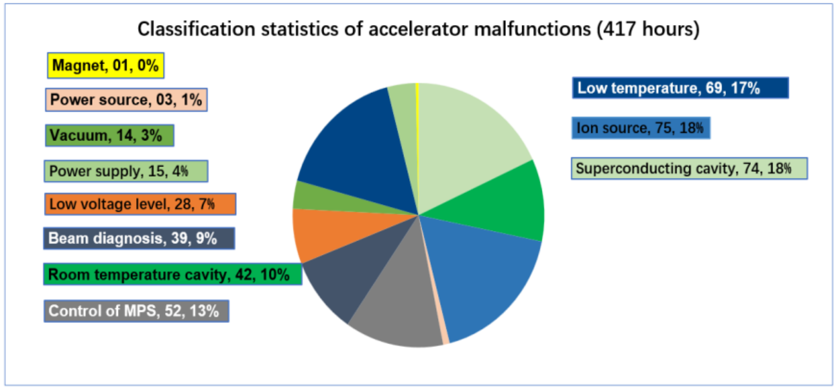
- The auto on and recovery feature was developed for all CAFe2 cavity
- The stability of SC cavity was significantly improved with the new LLRF

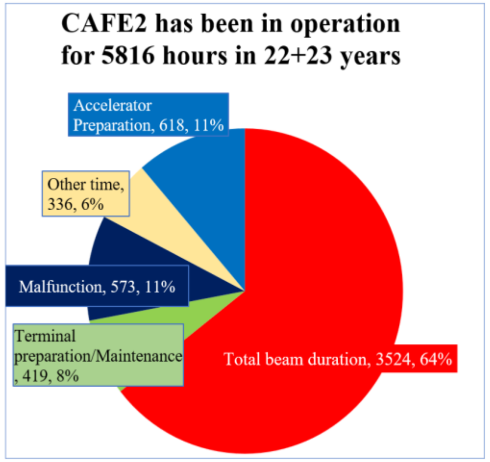
CAFe2 Operation Records

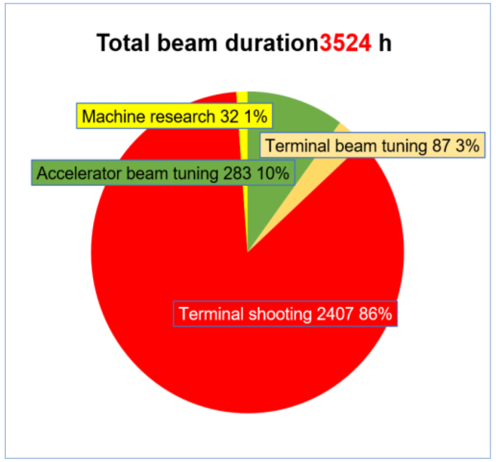


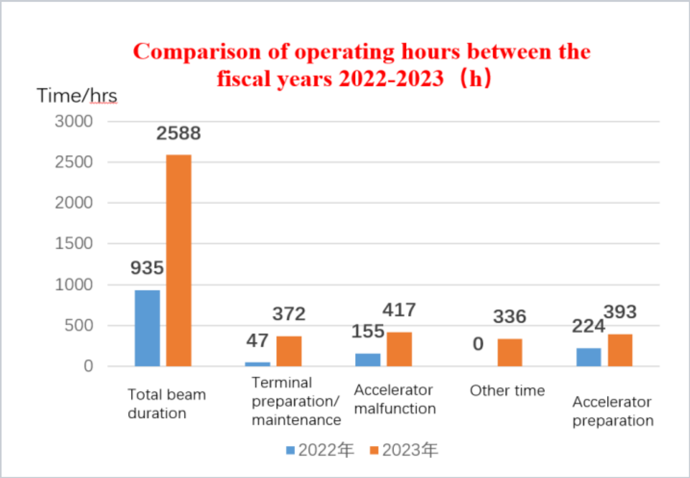
Statistics of SHANS Experiment Time (2022 ~2023)					
Particle	Accumulated Beam Hours	Targeting Hours	Particle	Accumulated Beam Hours	Targeting Hours
40Ar13+	248	248	40Ar12+	1302	1287
40Ca13+	962	717	48Ca14+	410	384
55Mn17+	232	134	54Cr17+	859	816

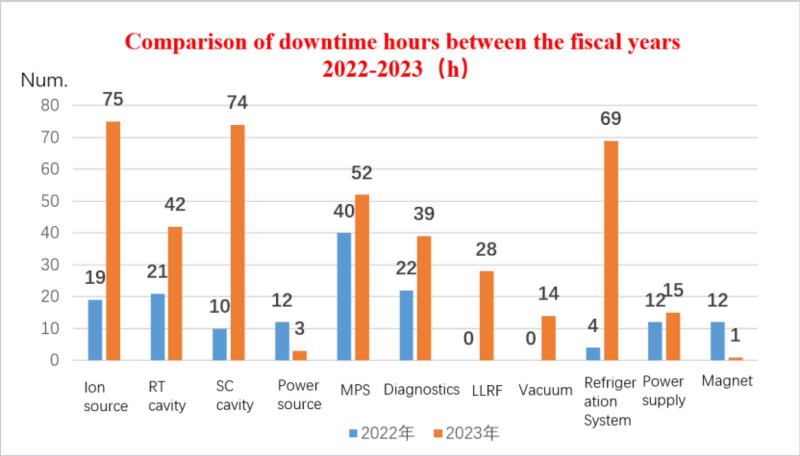
>90% Availability!





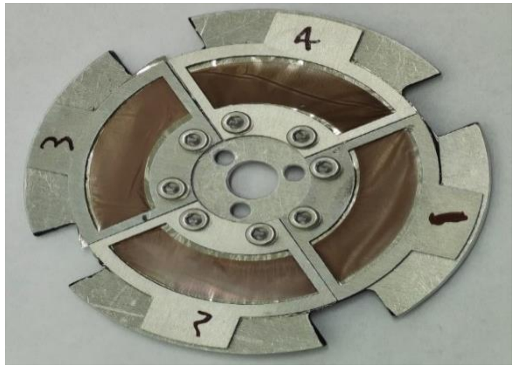


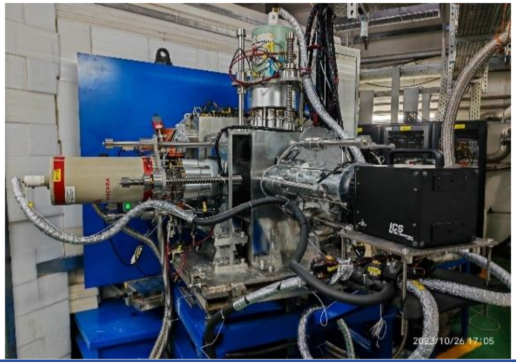




CAFe2 Recent Highlights

- **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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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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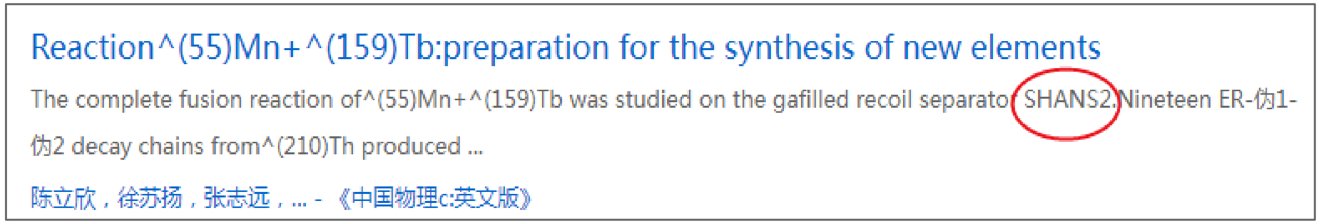
[d] Guangxi Key Laboratory of Nuclear Physics and Nuclear Technology, Guangxi Normal University, Guilin, 541004, China
[e] Joint Institute for Nuclear Research, Dubna, 141980, Russian Federation



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

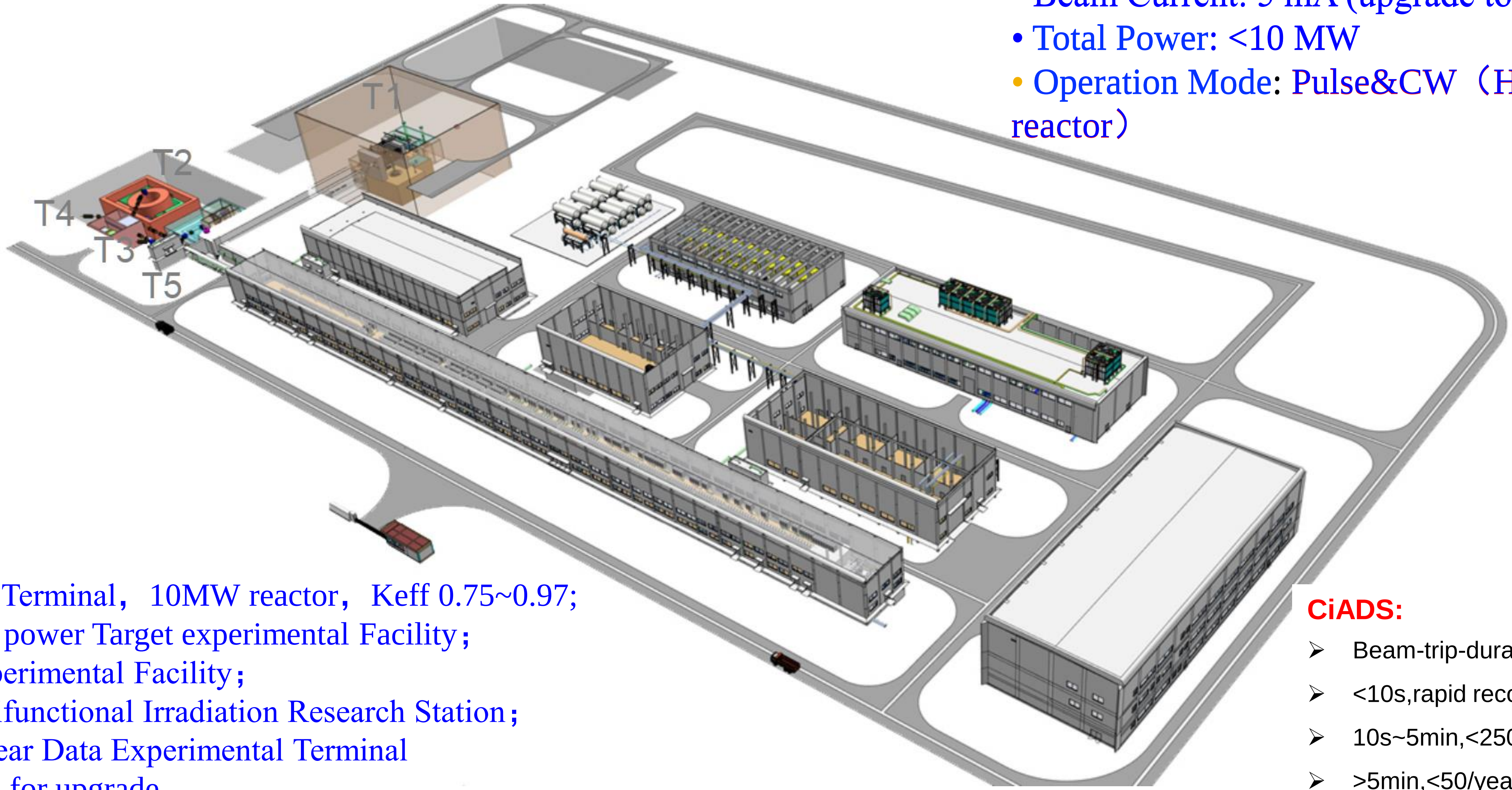
Brief introduction of CiADS project

- **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

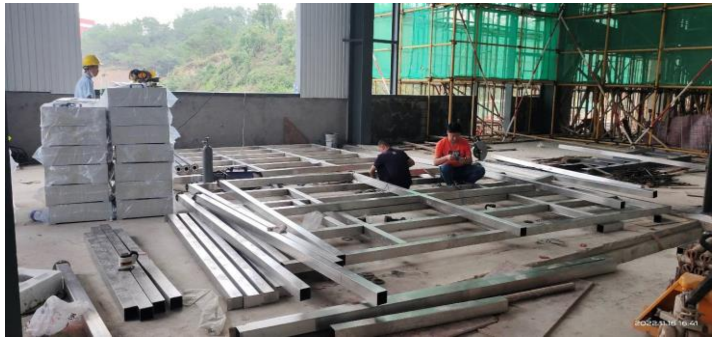
- RAMI - oriented
  - Redundancy design
  - Modular design
  - Fault-compensation scheme
  - Beam loss control
- Economy
  - High utility efficiency of Key components (cavity and SSA)
  - Well developed technology at IMP
  - More focus on the system integration and optimization (LLRF,ICS)
- Upgradeability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

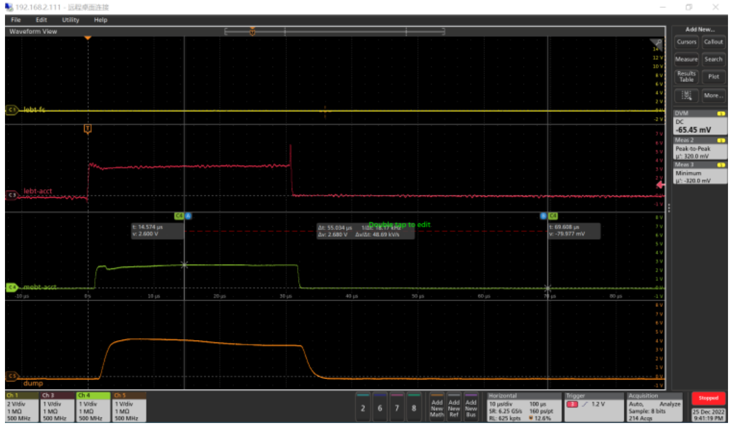
Main prameters of CiADS linac

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





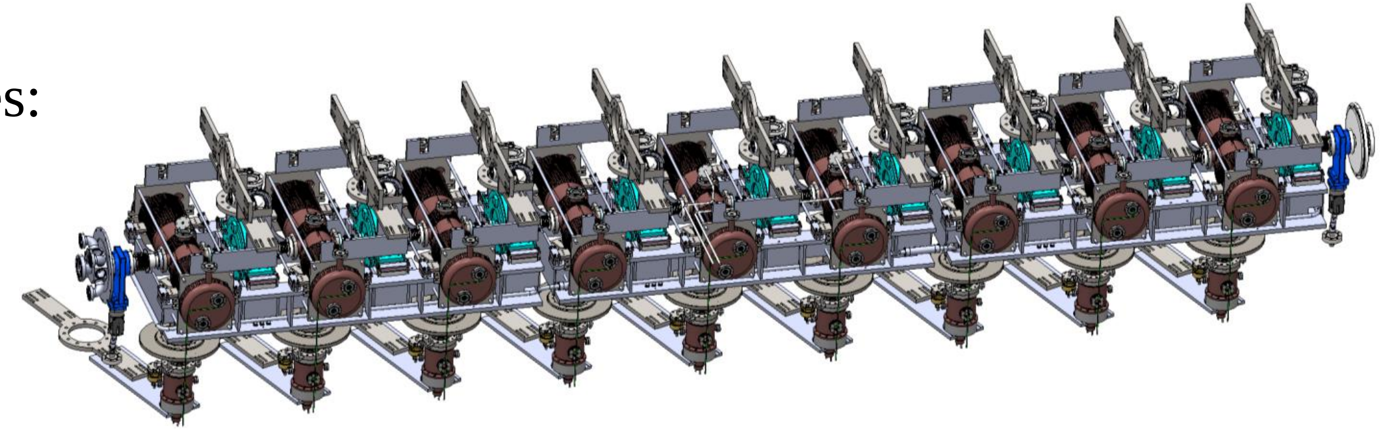
First beam of CiADS was commissioned in Dec. 2022, together with the construction of Huizhou Campus. Pulsed proton beam @ 2.18MeV, 5.2mA

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.



The world's first composite HWR cryomodule for HWR010

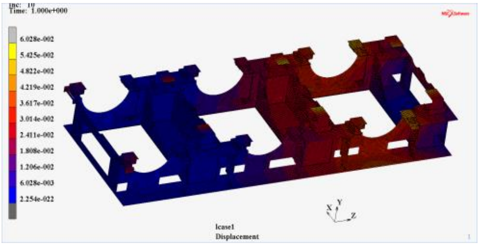
Nb/Cu cavities cooled by both LHe and conduction:

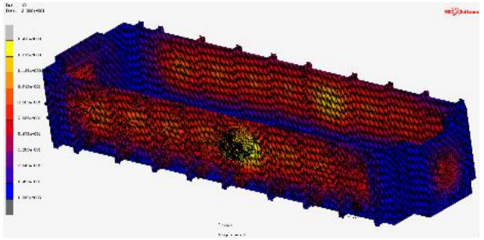
Design works:

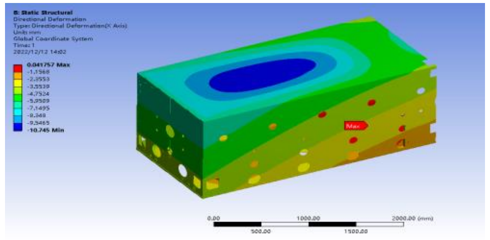
- Structure;
- Manufacture process;
- Pipelines;
- Heat load and LHe flow.

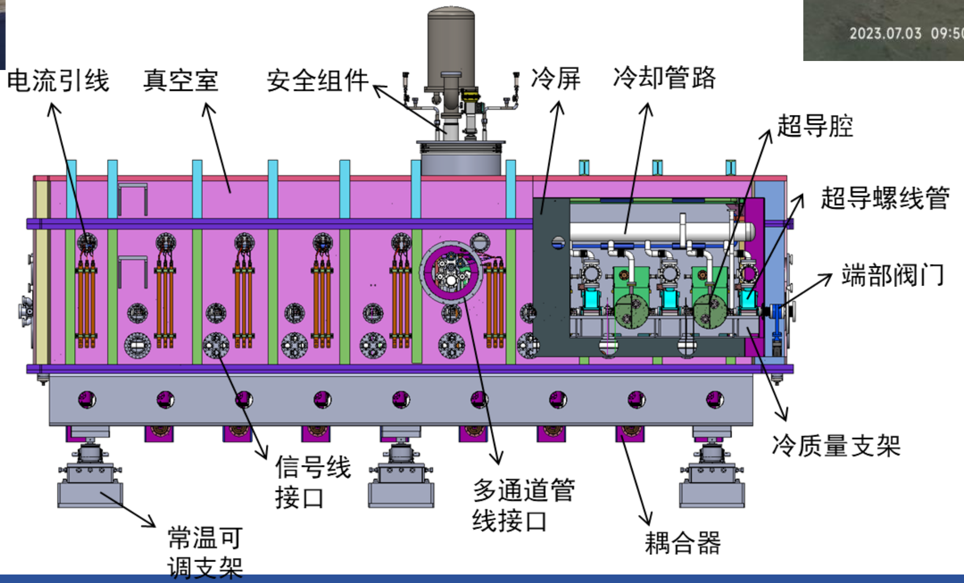
Manufacture works:

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









HWR040 1mm-wall Nb/Cu Cavities

Multiphysics

Parts

Bare cavities

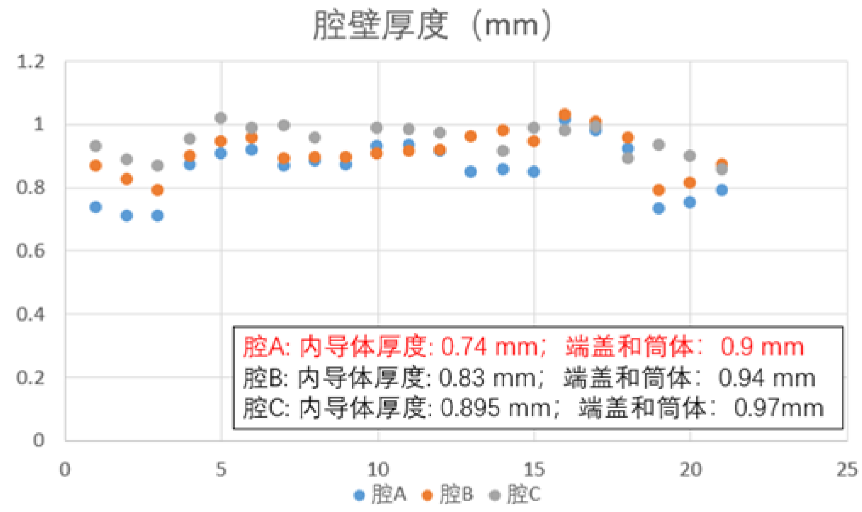
	Cavity A	Cavity B	Cavity C
Frequency (MHz)	325.07	325.58	325.56
Leak rate (mbar.l/s)	< 5.5E-6	< 6.1E-6	< 5.9E-6

Seeding layer

Electroplated copper

Final cavity

Cavity tuning



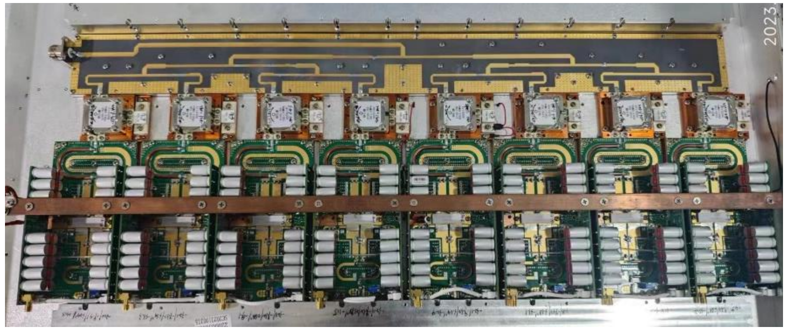
GaN Solid State Amplifier

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.

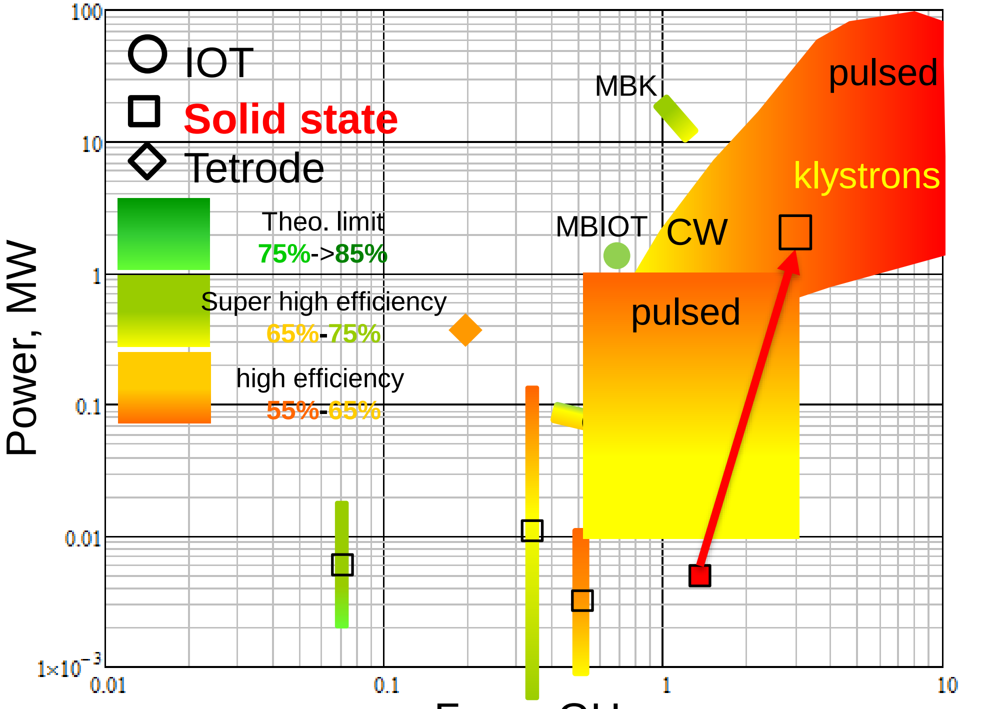
750Mhz功放板脉冲信号

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

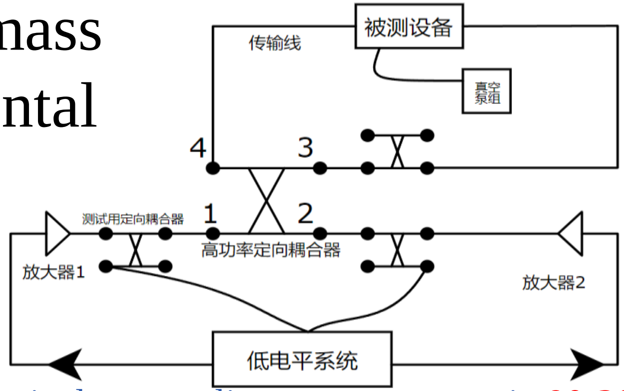
Plugin 25/50/100kW



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.

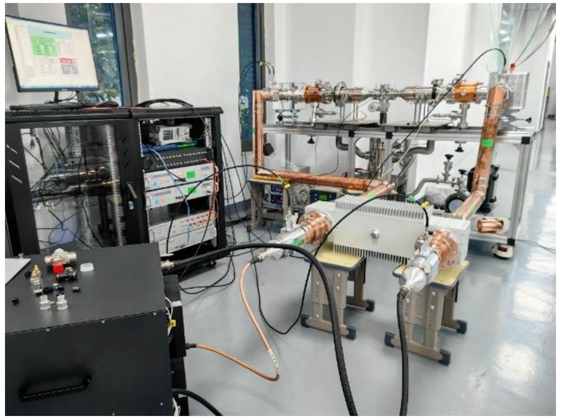
Fundamental Power Couplers

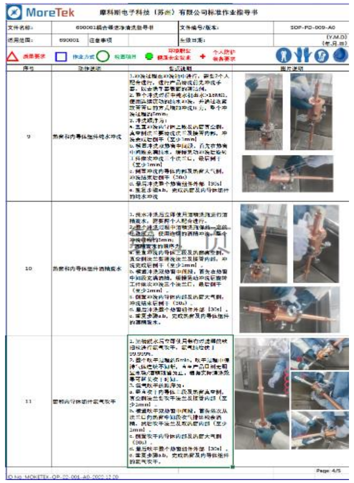
- Standard protocol and mass production for fundamental power couplers

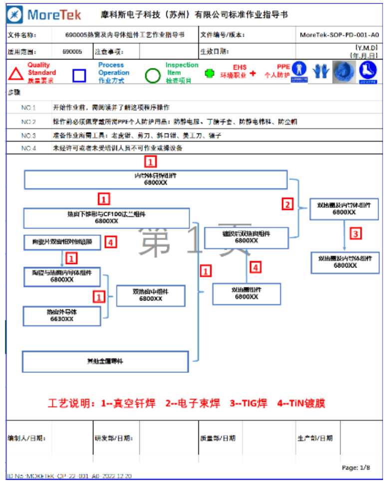


Equivalent traveling wave power gain 90-208

Harmonic conditioning




MoreTek 摩科斯电子科技（苏州）有限公司标准作业指导书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工艺说明：1--真空钎焊 2--电子束焊 3--TIG焊 4--TiN镀膜

3. HIAF-iLinac

Brief introduction of HIAF project

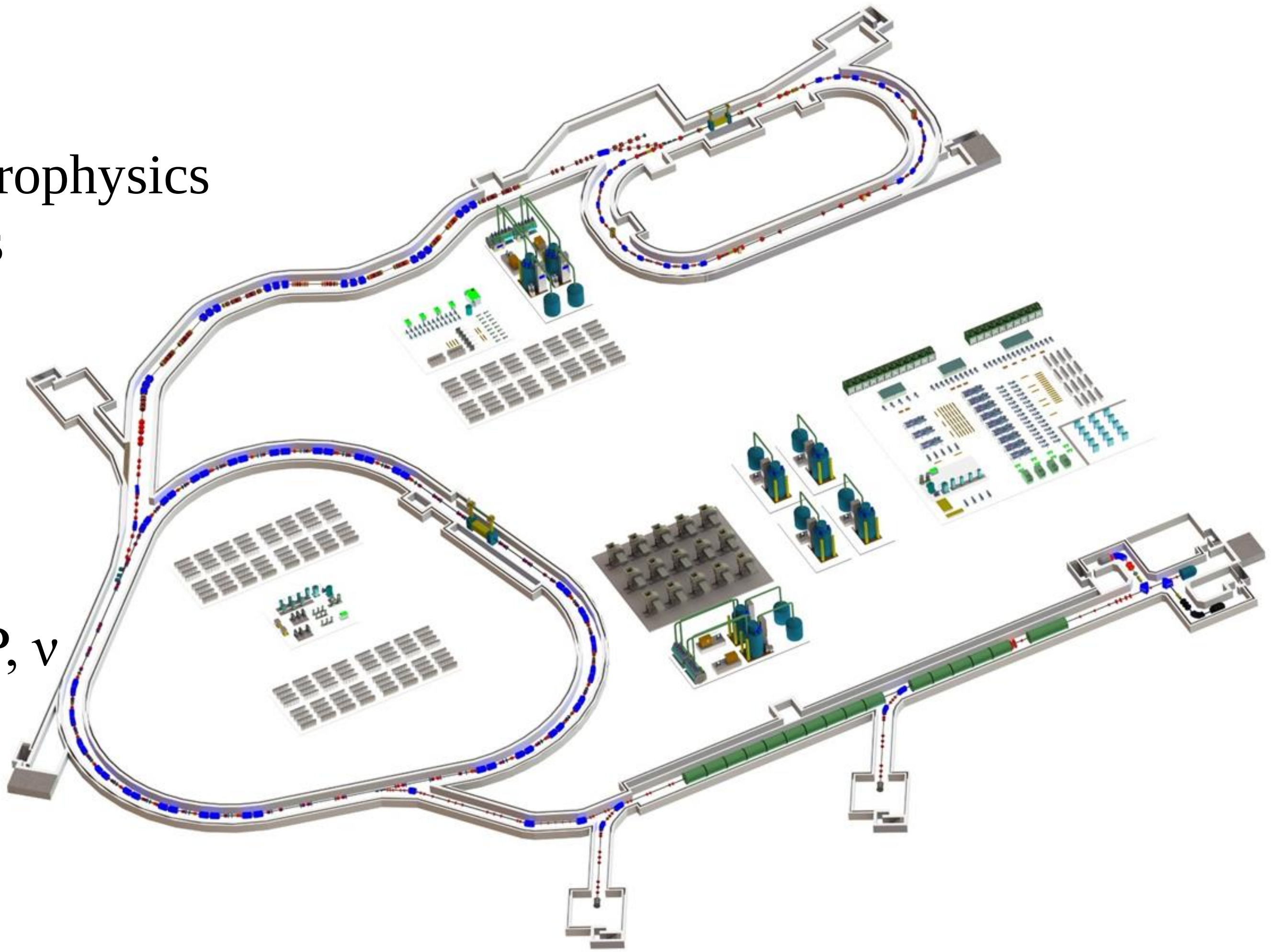
- Approved in Dec. 2015, Ground broke in August 2018, Officially started in July 2021
- Leading institute: IMP
- Budget: ~3 B CNY (Gov. 1.5B + Local Gov. 1.2 B)
- Location: Huizhou, Guangdong Prov.

Brief introduction of HIAF project

Scientific goals:

- Nuclear Physics
    - Nuclear Structure and Nuclear Astrophysics
    - Nuclear matter and hadron physics

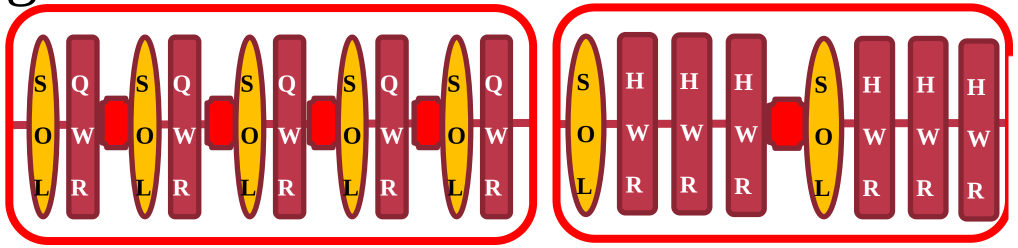
- Fundamental Physics
    - Ultra Strong Field QED
    - High Energy Density Matter
    - High brightness frontier: μ, k-rare decay and nucleon interactions, CP, ν
    - Electron-ion Colliding



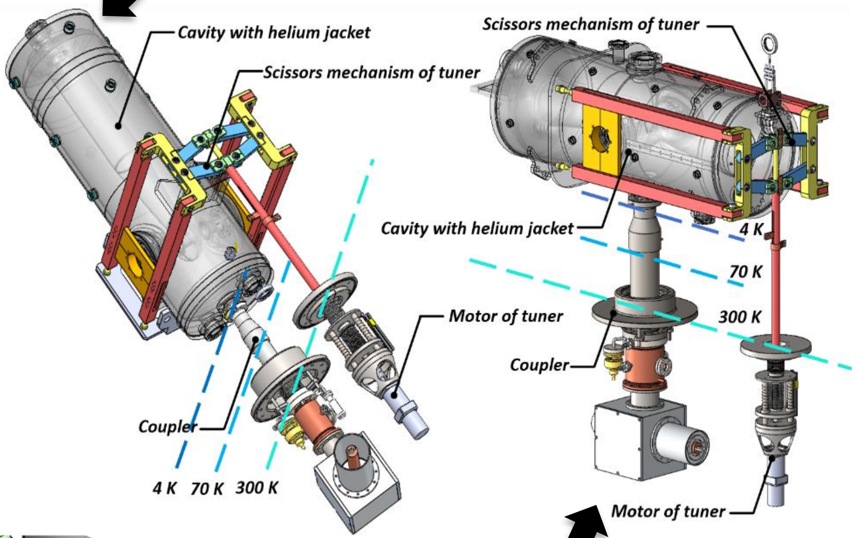
HIAF iLinac

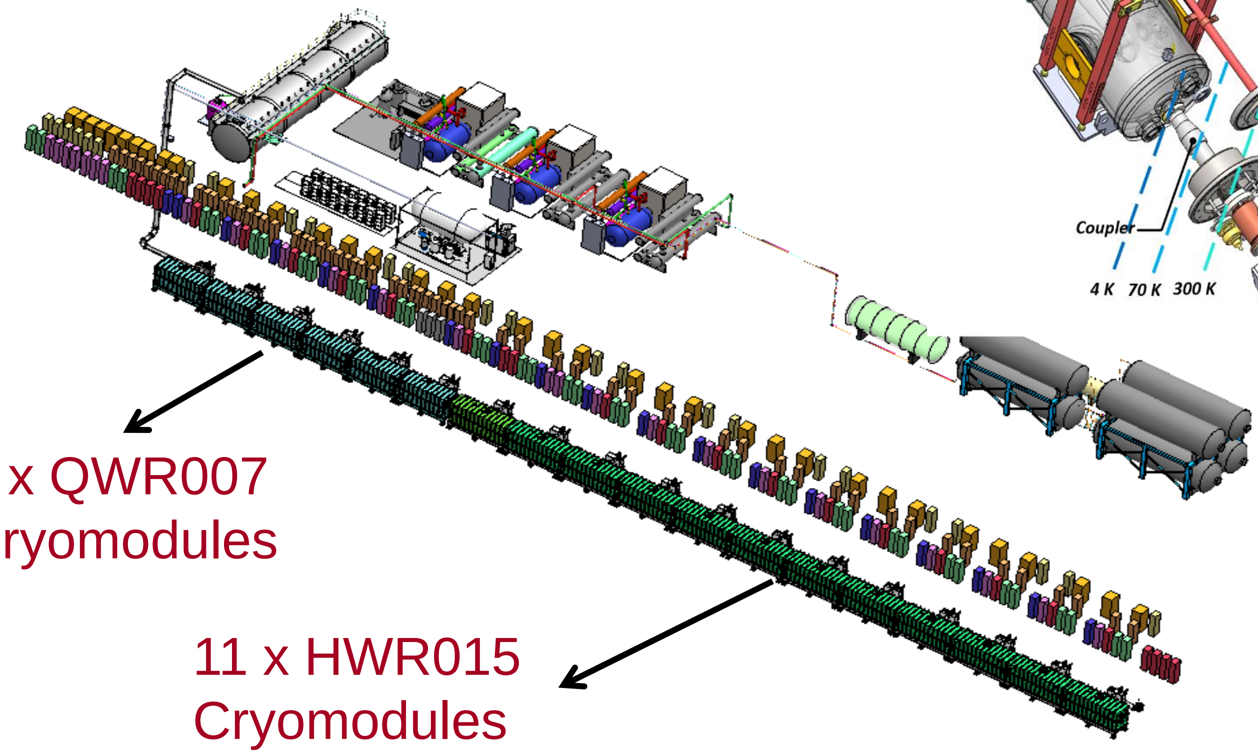
Cavities: QWR007 & HWR015

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



QWR007 with ancillary components





6 x QWR007 Cryomodules

11 x HWR015 Cryomodules

HWR015 with ancillary components

HIAF iLinac

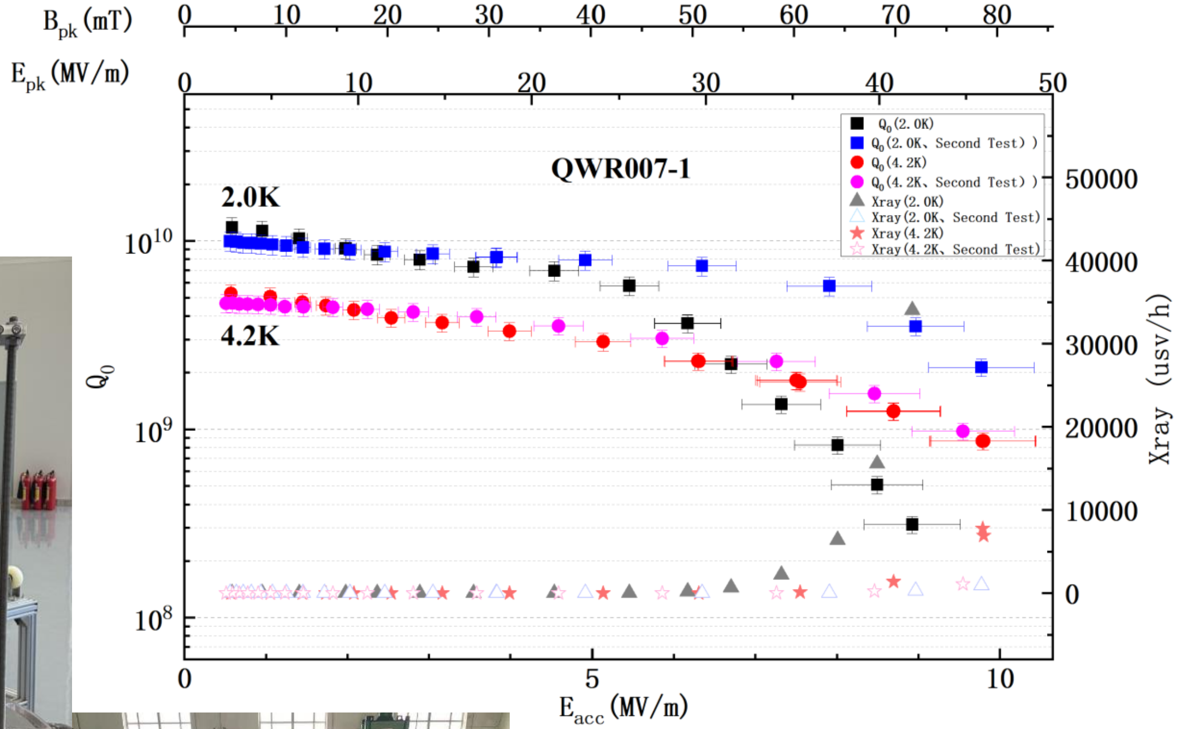
Cavity Fabrication and Test

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,

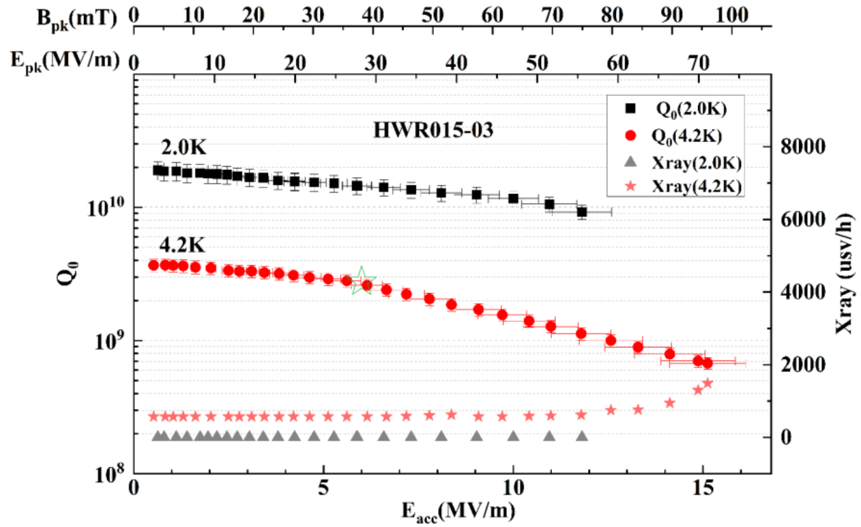
1 cav. tested @ 2K.

Both E_{pk}>70MV/m

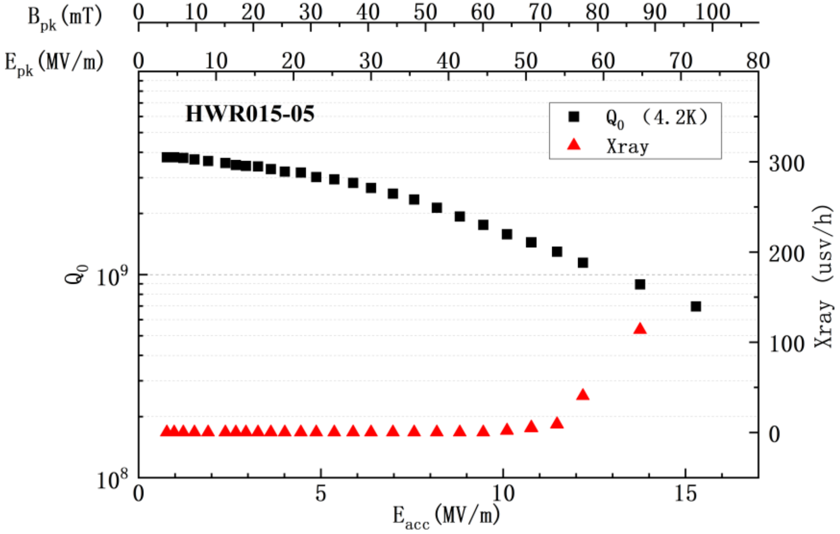
R_{res} < 6nΩ, meet HIAF specification:

Q_0=2.86E9 @2K

HWR015-3



HWR015-5



Traditional Cryomodule for Bulk Nb Cavities

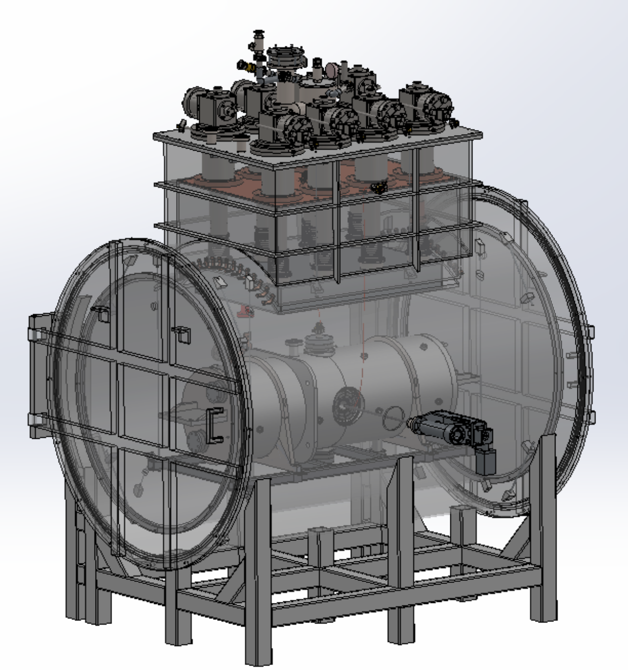
- Vacuum chambers, thermal shields, coldmass frames, G10 posts, and multi-channel pipelines have been finished for both QWR007 and HWR015 cryomodules.
- Both types have undertaken leak tests and thermal shock tests.
- Cryomodules are ready to be shipped to project sites as soon as the test bunker is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

Cavity Fabrication and Test

Single cavity dewar for VT:

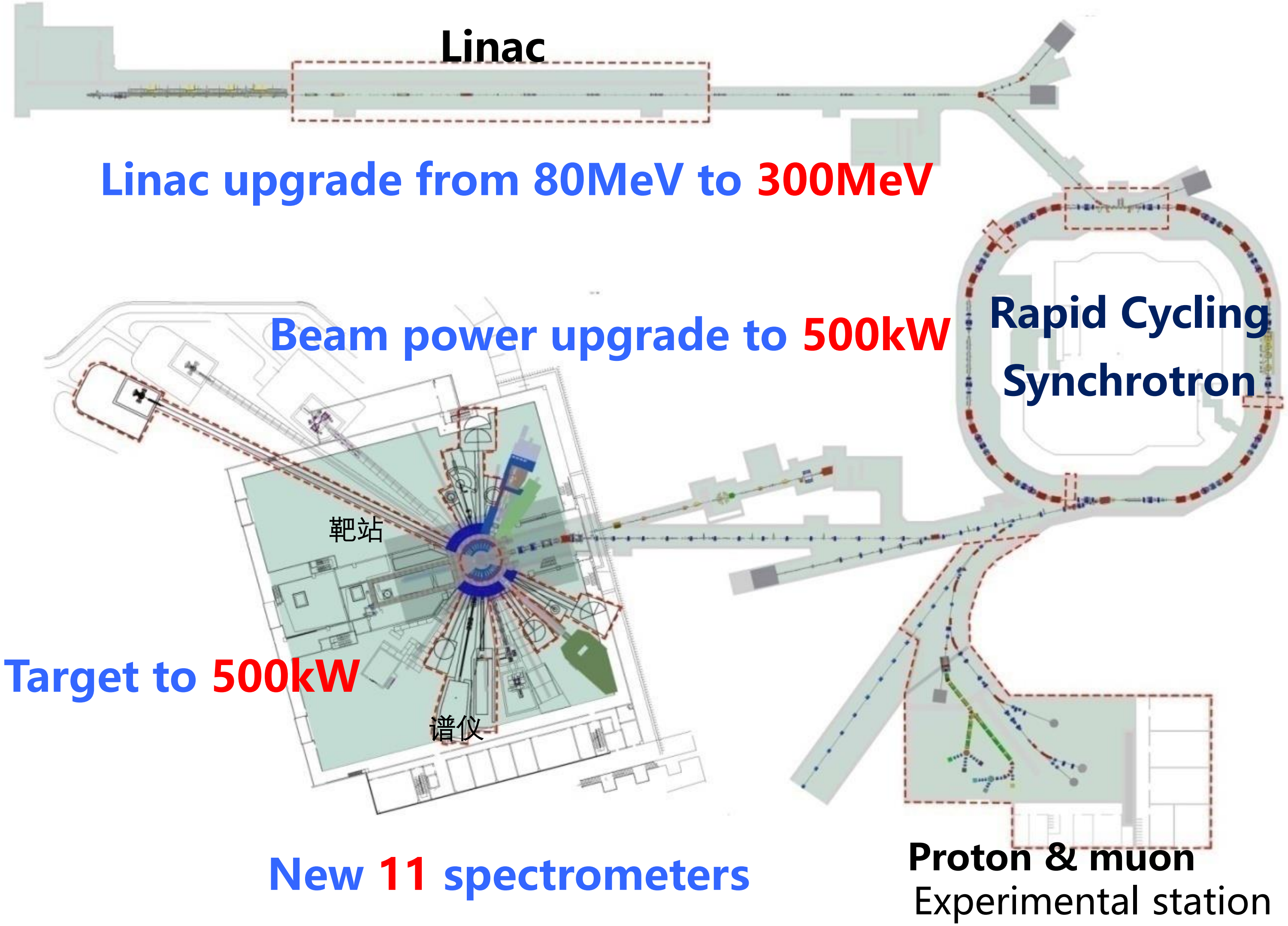
1. He-filled dewar @ Lanzhou
   8W static heat load;
   1 week installation time for each cavity;
   400L LHe capacity;
   1 cavity successfully tested.

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. CSNS-II

Brief introduction of CSNS-II



	CSNS	CSNS-II
Beam power (kW)	100	500
(Hz)	25	25
Target number	1	1
Average beam current (μA)	62.5	312
Proton beam energy (GeV)	1.6	1.6
RCS injection beam energy MeV)	80	300
Number of Spectormeters	3	11+8

- Construction duration: 69 months； Keep operation for user during upgrade

Brief introduction of CSNS-II

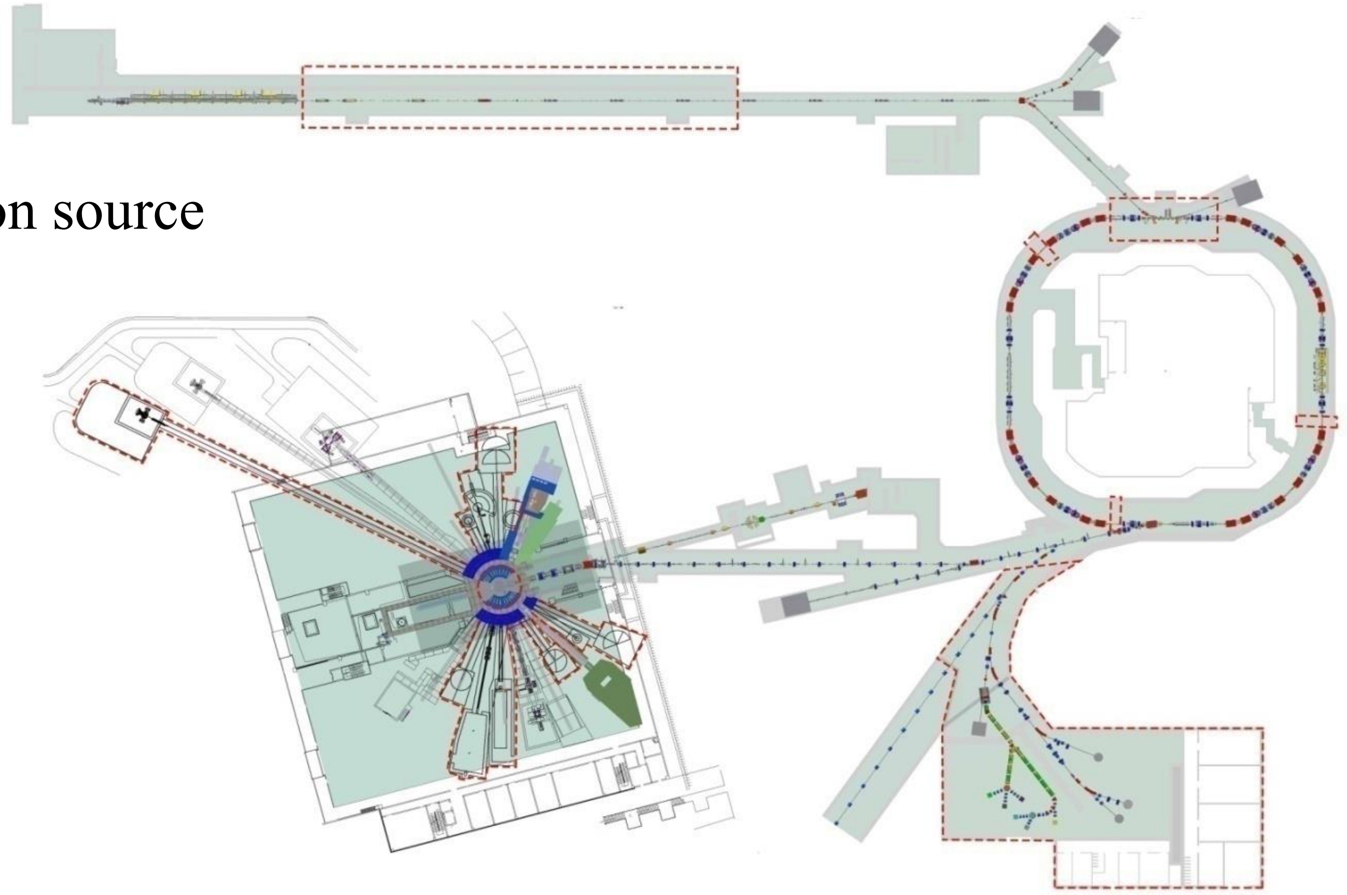
Major upgrade items

Linac R&D: Upgrade to 300MeV, 40mA+

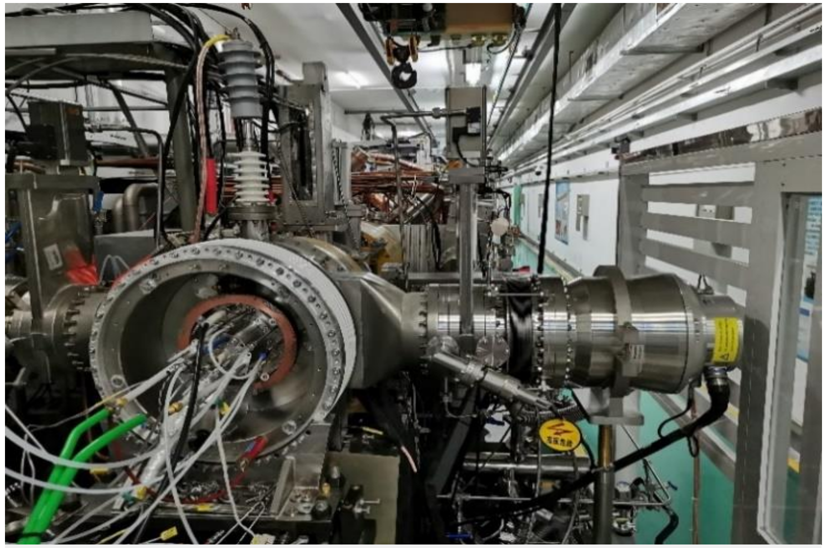
- Newly developed RF-driven H− ion source
- Superconducting linac
- RF power source

RCS R&D: Upgrade to 500kW

- Beam dynamics
- High power MA loaded cavity
- New injection painting



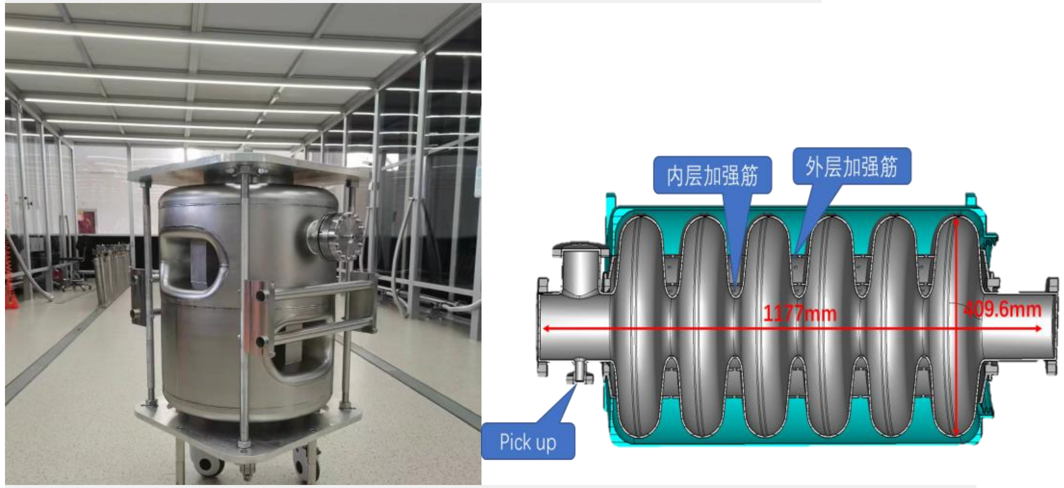
R&D for CSNS-II Accelerator



RF H^- ion source

MA second harmonic cavity

7-cell pi-mode debuncher



Prototype SC cavities: Double spoke & Ellipsoidal cavity

Long-pulse solid-state modulator

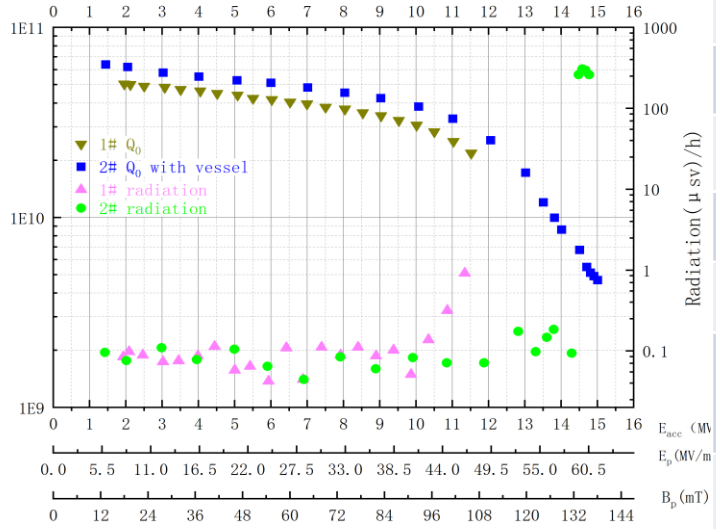
Low-level RF prototype

R&D for CSNS-II Accelerator

Spoke Cavity Prototyping

The prototype of DSR

The prototype of cavity with vessel



Vertical testing data of the prototype

parameter	prototype	improved
Frequency(MHz)	324	324
β_{opt}	0.5	0.5
E_p/E_{acc}	4.1	3.44
B_p/E_{acc}(mT/(MV/m)^2)	9.2	8.86
R/Q (Ω)	410	401
G (Ω)	120	118
Beam tube diameter (mm)	50	50
E_{acc}(MV/m)	7.3	9

The parameter of DSR

- ✓ Two double spoke cavity prototypes have been fabricated and tested, the maximum Eacc reaches at 15 MV/m, and the Q is above 4E10 at 7.3MV/m.
- ✓ Based on the experience gained in the prototyping, we improved the cavity design and process to enhance the performance further.

R&D for CSNS-II Accelerator

HPR

Coupler installation

Bellows installation

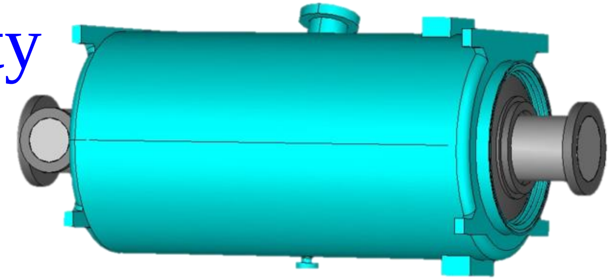
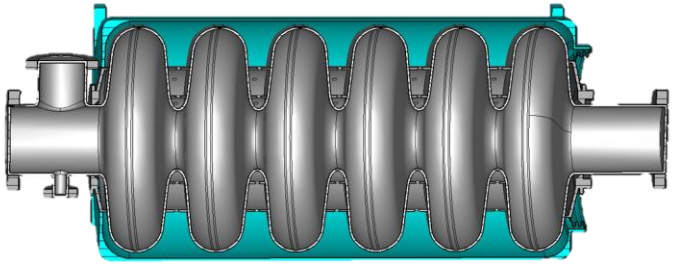
Cavity string assembly

- The cavity string assembly in the clean room is Completed
The cryomodule and valve box have been delivered to PAPS.
- The installation of the cryomodule and valve box will be finished in Dec. 2023

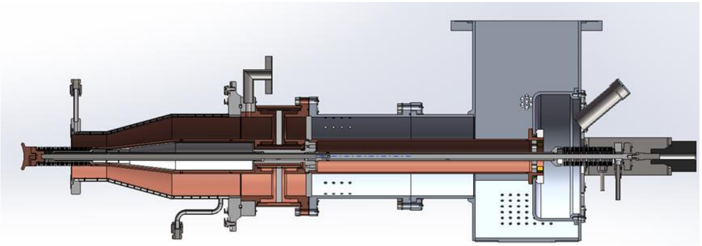
R&D for CSNS-II Accelerator

648 MHz 6-cell elliptical Cavity

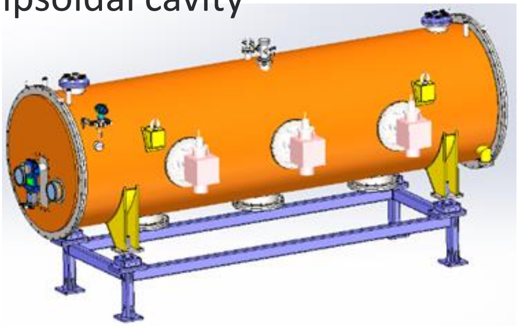
parameter	design
Frequency(MHz)	648
TTF@β_g	0.7
β_g	0.62
E_p/E_{acc}	2.53
B_p/E_{acc}(mT/(MV/m)2	5.45
R/Q（Ω）	309
G（Ω）	177
Beam tube diameter (mm)	105/120
Cell-cell coupling（%）	1.35
E_{acc}(MV/m)	14

mechanical structure of ellipsoidal cavity



The mechanical design of coupler



The cryomodule structure

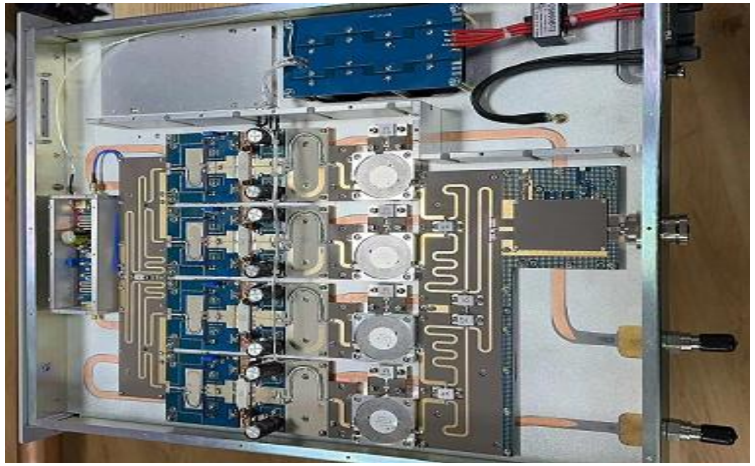
End cover

- ✓ The design of the superconducting cavity, coupler, magnetic shield, and tuner has been completed.
- ✓ The cryomodule is currently under design.
- ✓ The cavity is currently being fabricated.

R&D for CSNS-II Accelerator

RF power source

- A separate power source for each cavity, to adjust power and phase
  - 300kW @ 324MHz * 20
  - >500kW @ 648MHz * 24

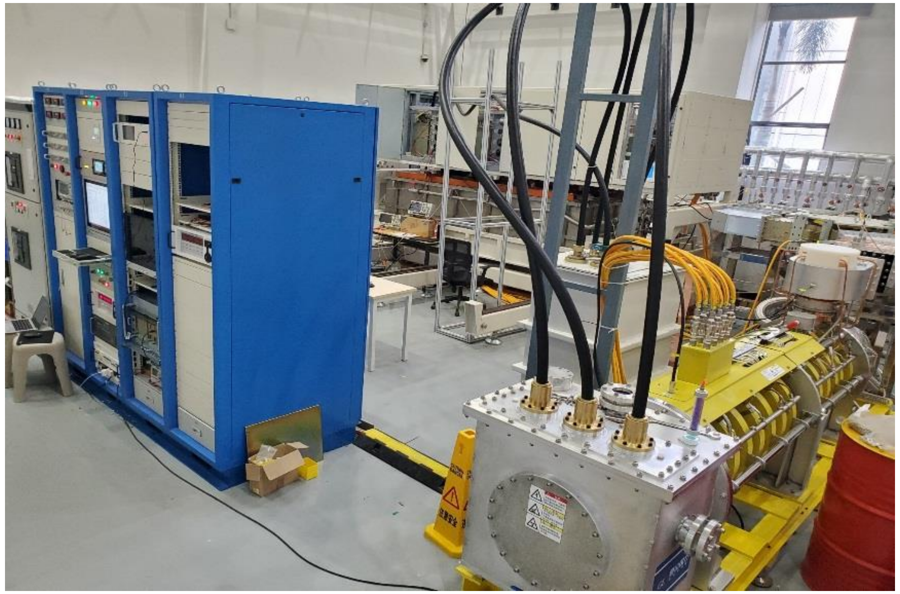


● Spoke cavity

Solid state amplifier, with 30% safety margin

● Elliptical cavity

Klystron + solid modulator + circulator and load



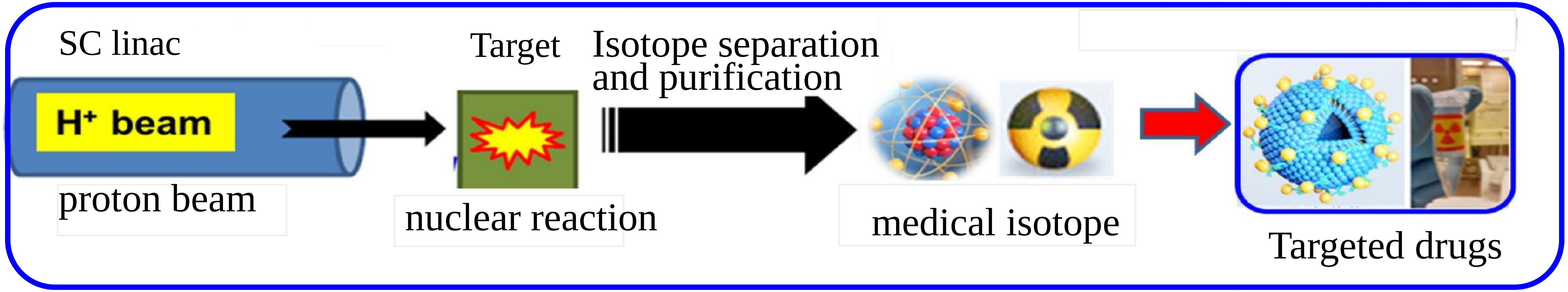
5. IP-SAFE

Brief introduction of IP-SAFE

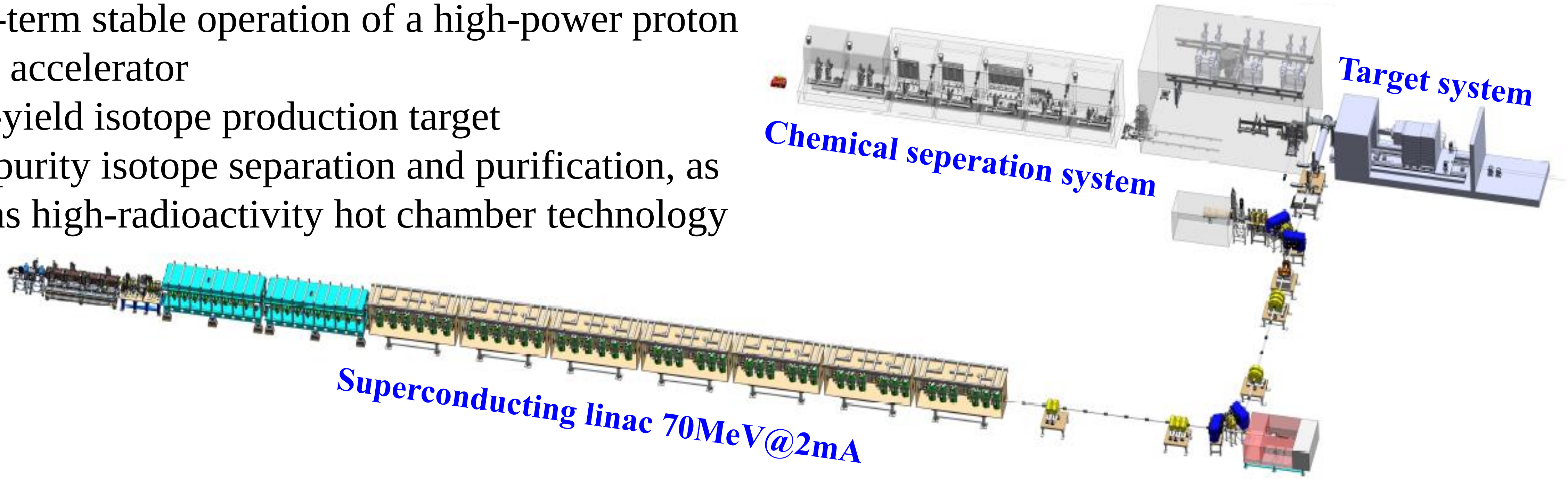
Isotope Pharmaceutical Production Platform based on Superconducting Accelerator Facility for Effective therapy (IP-SAFE)

- **The feasibility study report has been passed in September 2023,**
- **Leading institute: IMP**
- **Budget: ~5 B CNY**
- **Location: Lanzhou, Gansu Prov.**

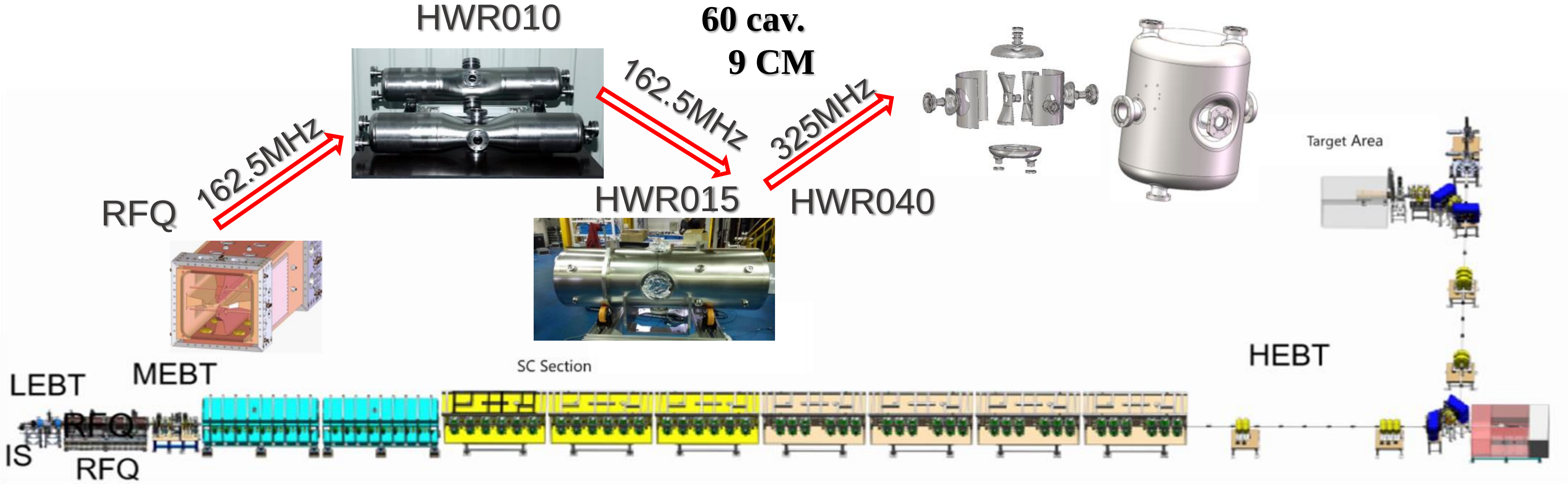
Brief introduction of IP-SAFE



- Long-term stable operation of a high-power proton linear accelerator
- High-yield isotope production target
- high-purity isotope separation and purification, as well as high-radioactivity hot chamber technology



IP-SAFE Superconducting Linac



Design philosophy for SC Linac

- RT Front: beam shape and emmissivity
- SC section: Stable and low beam loss
- HEBT: Beam on target, control and monitoring.

World's first HB proton machine for α-medicine production

Parameters

	Value	Unit
Particle	H^+	-
Energy	70-100(upgrade)	MeV
Beam Int.	1-2	mA
Freq.	162.5 / 325	MHz
Int. stability	< 1%	-
E stability	< 0.1%	-

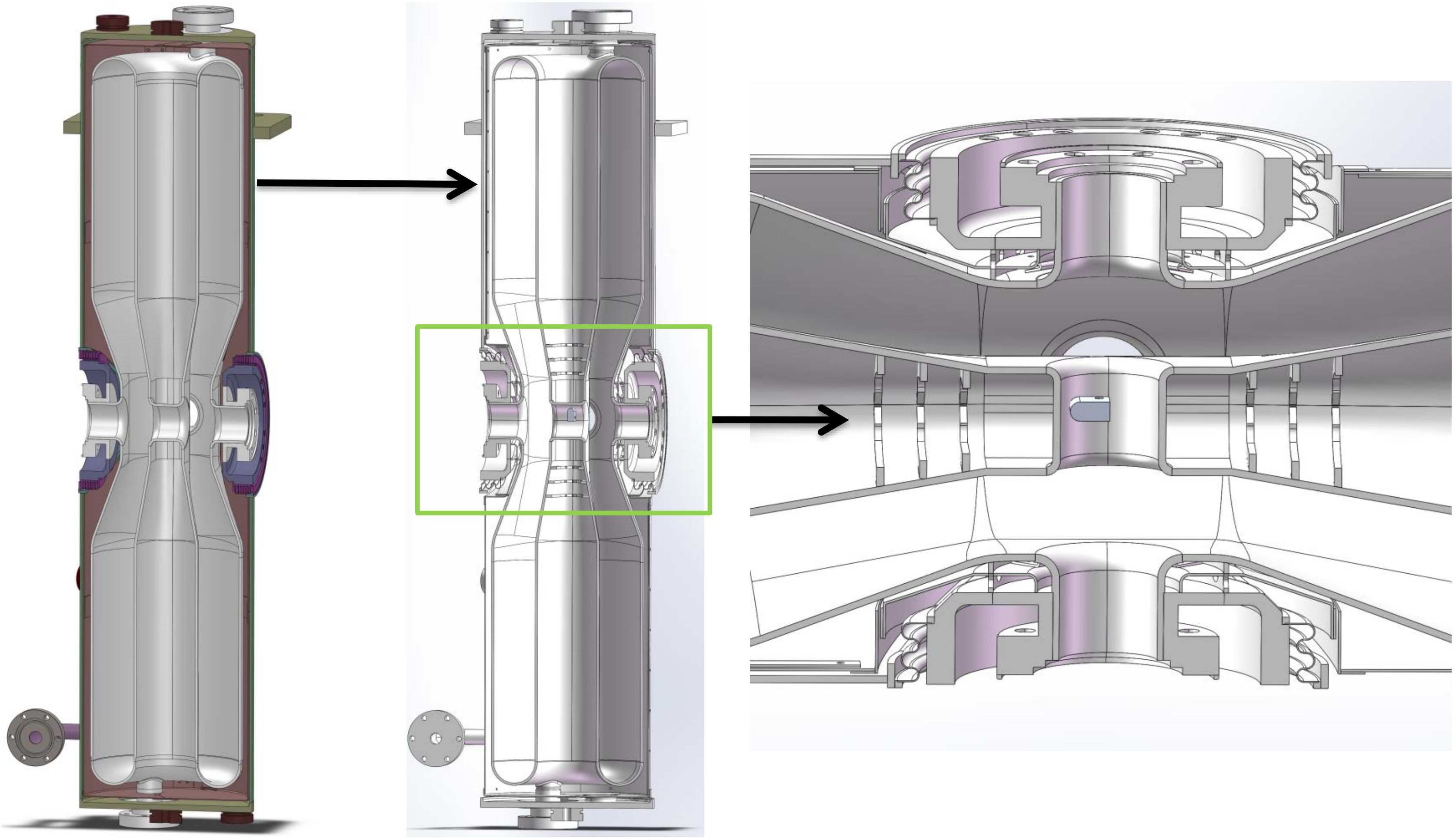
IP-SAFE Superconducting Linac

Cavity Parameters: all bulk Nb cavities

Parameters	HWR010	HWR015	HWR040
Freq.[MHz]	162.5	162.5	325
β	0.10	0.15	0.40
# of Cell	2	2	2
aperture[mm]	40	40	40
Epk_VT[MV/m]	28	30	30
Epk_Operation[MV/m]	26	28	28
Veff_Operation [MV]	0.84	1.67	2.69
Length[mm]	210	330	450
Operation T[K]	4.2K	4.2K	4.2K
RF mode	CW	CW	CW

HWR010 for IP-SAFE

- Improved from CAFe2 project.
- Center conductors are optimized for cooling efficiency.
- Designed both for 2K and 4.2K.



Emerging Projects

2. HIAF iLinac

energy 150 MeV/u

current 2 emA

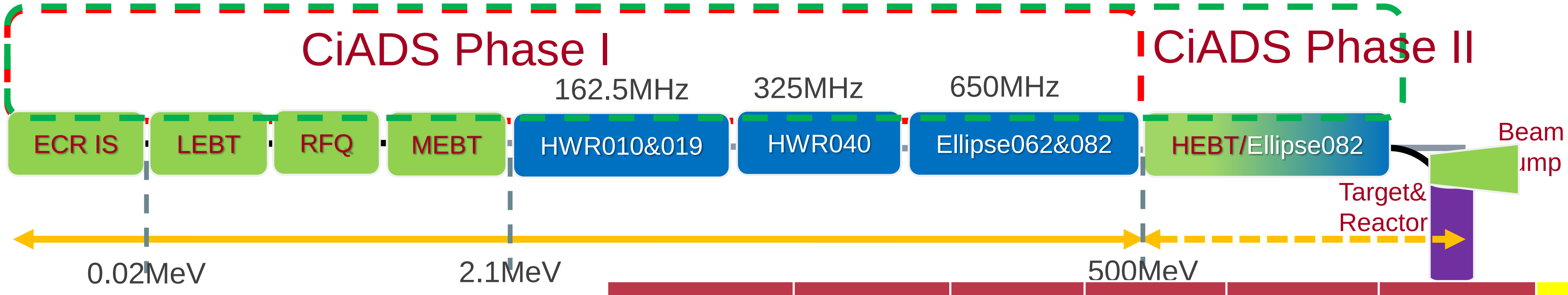
for high desity matter and EICc

1. CiADS upgrade plan

energy 1.5 GeV
beam current 10 mA

for muon source and commecial ADS

1. CiADS Beam Intensity Upgrade



CiADS SC Linac upgrade:

Beam Power: 10-15MW

Pulse & CW

Operation parameters:

Receiving E: 2.1 MeV

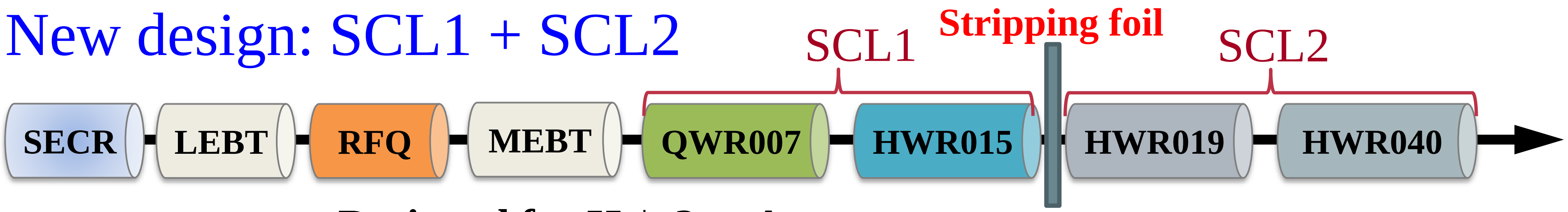
Output E: 1-1.5 GeV

Beam Int.: 10 mA

Beam Loss: < 1W/m

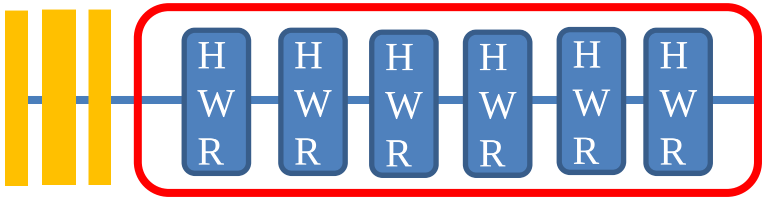
	HWR 010	**HWR 019**	**HWR 040**	**Ellip 062**	**Ellip 082**	**Ellip 082**
Freq.(MHz)	162.5	162.5	325	650	650	650
Cav. β_{opt}	0.10	0.19	0.40	0.62	0.82	0.82
Cav. cell#	2cell	2cell	2cell	6cell	5cell	5cell
Cav. E_{pk} (MV/m)	26/30	28/33	28/33	28/33	28/33	28/33
# of Cav.	9	24	60	30	28	68
Magnets	SC Solenoids	SC Solenoids	SC Solenoids	RT triplet	RT doublet	RT doublet
# of Magnets	9	24	20	10	6	6
B (T)	7.5	7.5	7.5	0.9	0.9	0.9
# of CM	1	4	10	10	7	17
Total # of Cav.	151 + 68					
Length(m)	~200 + 84					

New design: SCL1 + SCL2

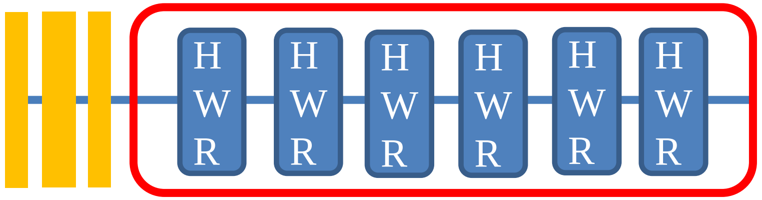


Designed for H_3^+, 2emA

HWR019



HWR040



	SCL2	
Cav. type	HWR019	DSR042
Freq. (MHz)	162.5	325
E_{acc} (MV/m)	28(Quasi-CW) / 32(Pulsed)	28(Quasi-CW) / 32(Pulsed)
Focusing Elements	Quadruple	Quadruple
# of CM	5	10
# of Quadruple Magnets	15	30

Conclusions and Perspectives

Hadron Accelerator Projects:

- SRF is essential for new state-of-the-art hadron machines.

- Fundamental Physics still calls for higher ***E***, higher ***I***, higher ***P***

- Aside from Energy, Intensity, Power, various application directions are emerging.

Acknowledgment

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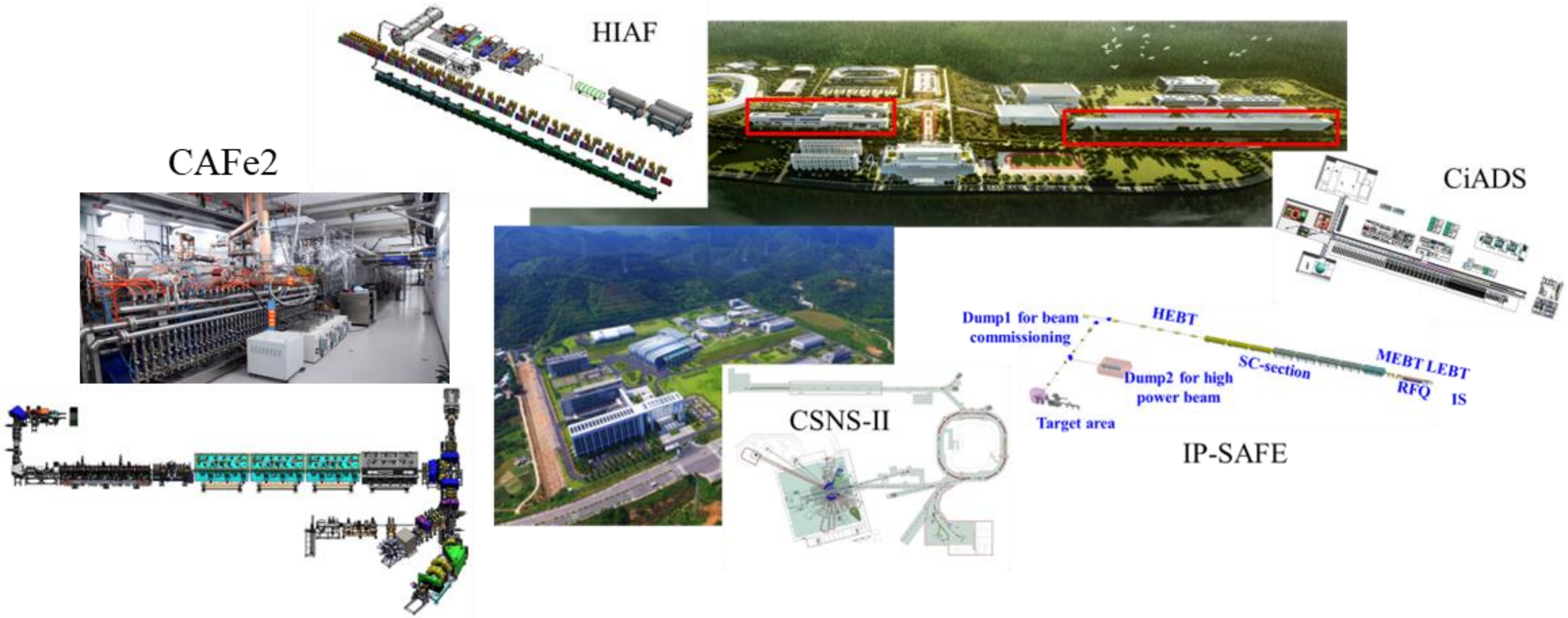
Huachang Liu



Thank you for your attention!

Questions?