TESLA TECHNOLOGY
TTC
COLLABORATION

Progress on SRF technology in China

Teng Tan

On behalf of China SRF community

2020-Feb-06

Outlines

1. Demands: SRF projects in China
2. Supplies: SRF tech. researches in China
3. Supply-and-demand
4. Prospects

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Active China SRF projects

Project	Location	Cavities	Comments
BEPC-II	Beijing	2	2x500 MHz elliptical cavities, commissioned
CTFEL	Chengdu, Sichuan	2	THz FEL, commissioned in 2017
CAFe	Lanzhou, Gansu	23	Front-end demo for CiADS, commissioned in 2017, 50 kW cw proton beam.
SHINE	Shanghai	616	X-ray FEL, under construction
CiADS	Huizhou, Guangdong	137	1 MW cw proton beam, under construction
HIAF	Huizhou, Guangdong	96	HI injector, from H to U, under construction
HEPS	Beijing	7	Hi-lumi FEL, under construction
CEPC	Hebei*	336	Proposed, accelerator CDR published in 2018
CSNS phase-II	Dongguan, Guangdong	~100	Proposed, in 5 years
Gansu Isotope Factory	Lanzhou, Gansu	30	Will be funded by local government, high power proton and HI.

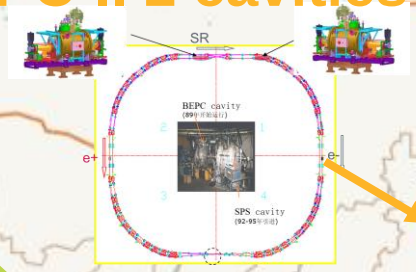
Status

- Construction
- Commissioned
- In Design

HEPS, 7 cavities

CEPC, 336 cavities

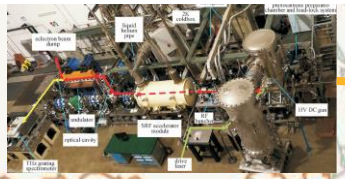
BEPC-II 2 cavities



Isotope Factory
30 cavities

CAFe 23 cavities

CTFEL
2 cavities



CSNS upgrade
~100 cavities

CiADS & HIAF
233 cavities

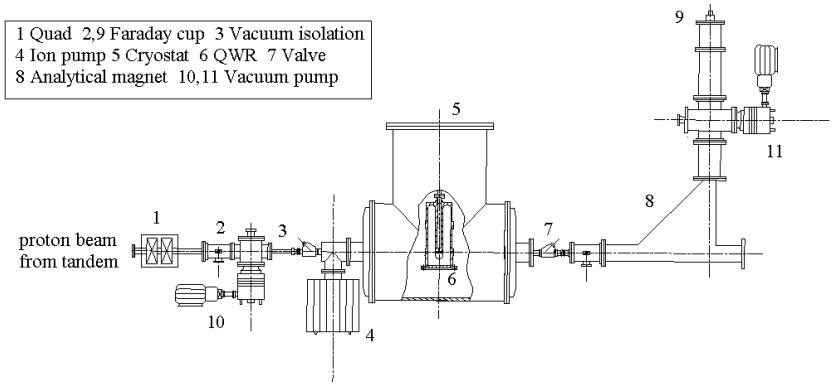
SHINE 616 cavities

北京

黄海

东海

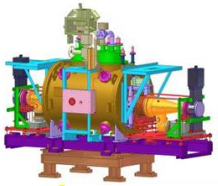
Evolution of Projects

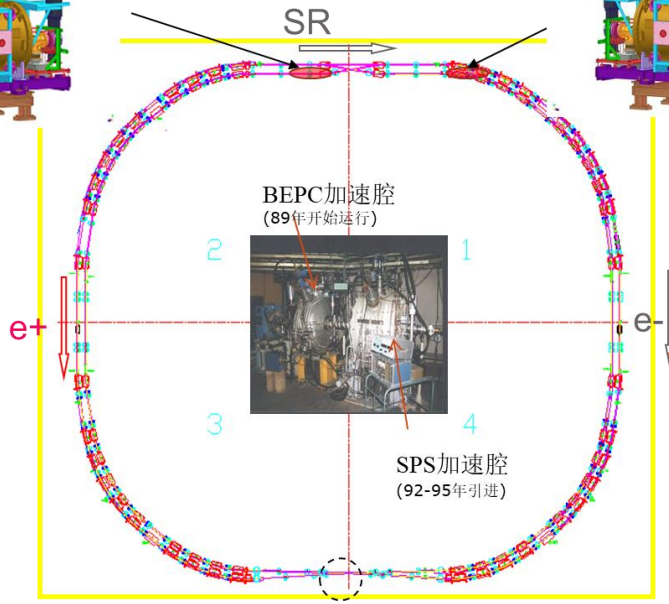


1990 2000 2010 2020

2001 PKU Nb/Cu QWRs for proton. First cavity online, but failed in the online test.

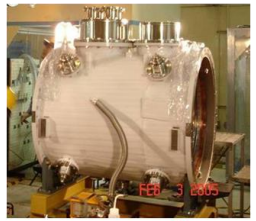
Evolution of Projects

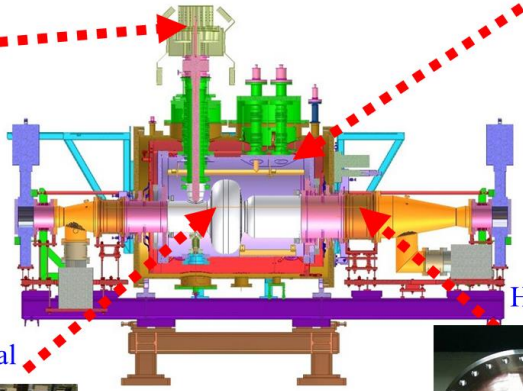




FPC

Cryomodule





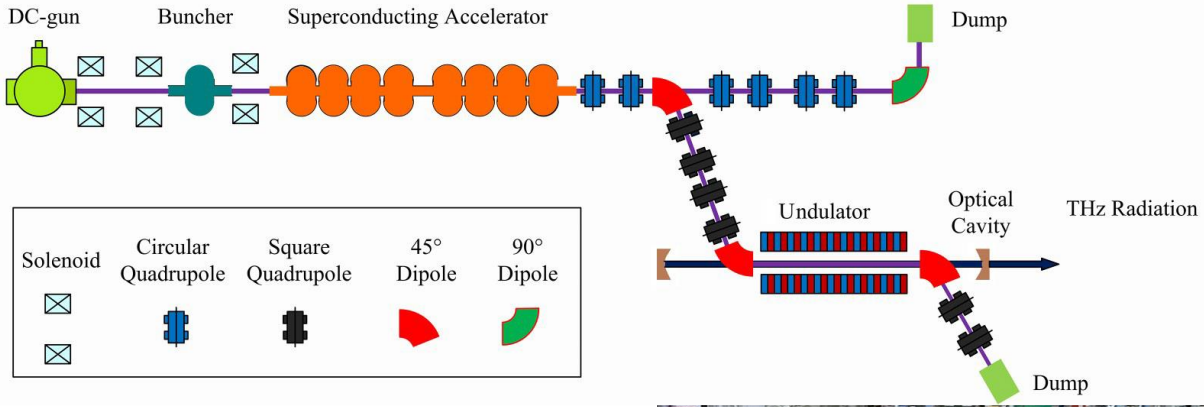
HOM absorber

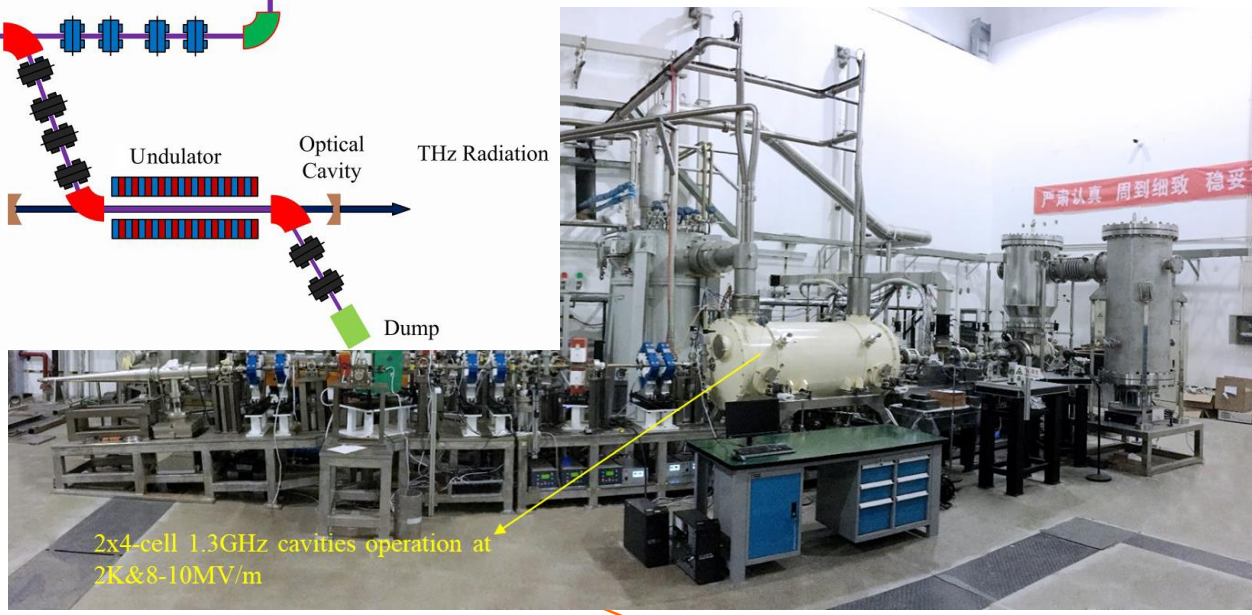
500 MHz elliptical

1990 2000 2010 2020

2004-2006 IHEP BEPC-II upgrade, first cavity with FPC, HOM coupler, CM, and etc. The Milestone for China SRF.

Evolution of Projects





1990 2000 2010 2020

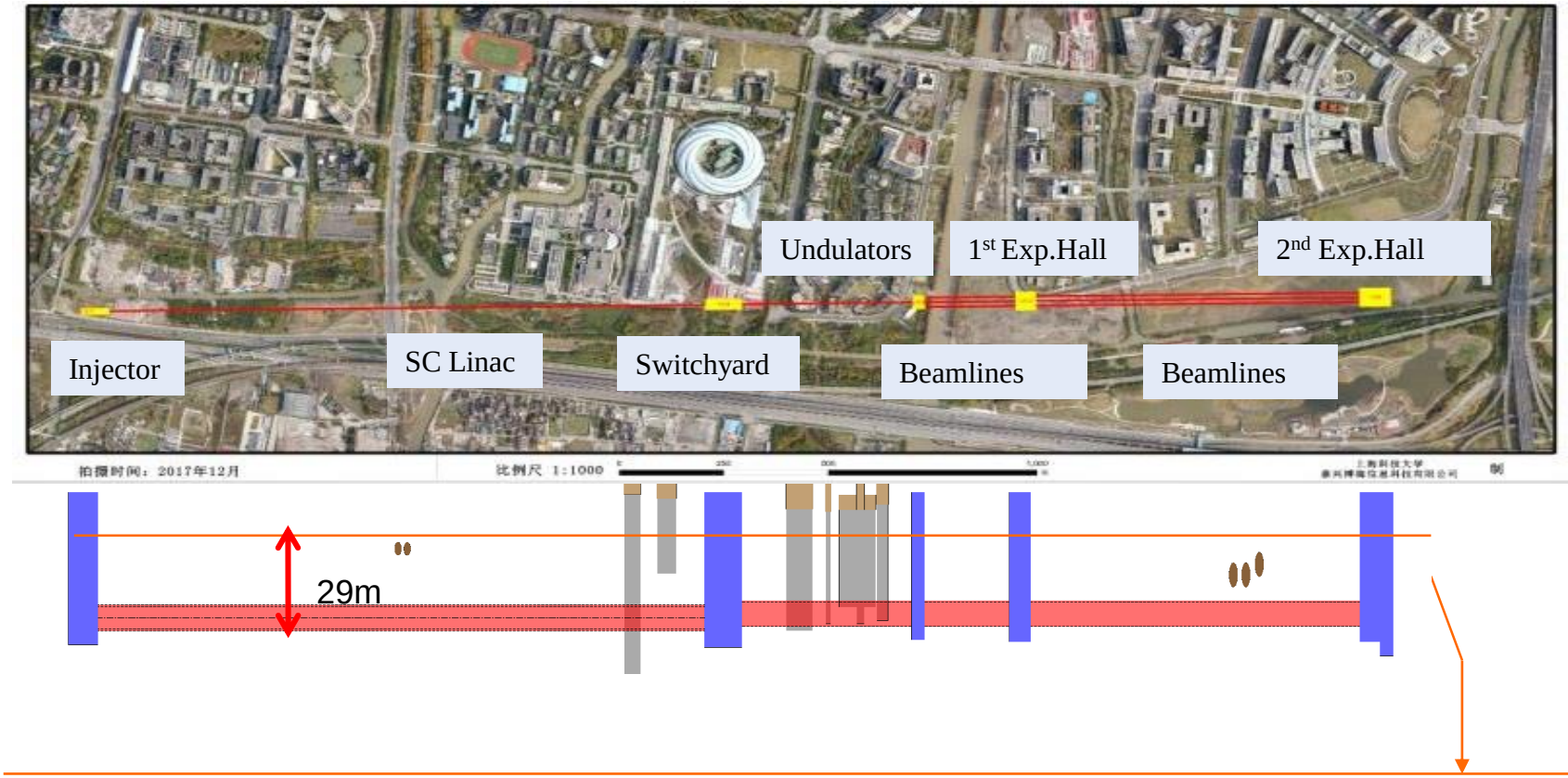
2012-2017 CTFEL, CAEP & PKU, 2 x 4-cell Tesla type cavities.
2 K operation. Max 8 MeV, 5 mA cw e-beam.

Evolution of Projects

1990 2000 2010 2020

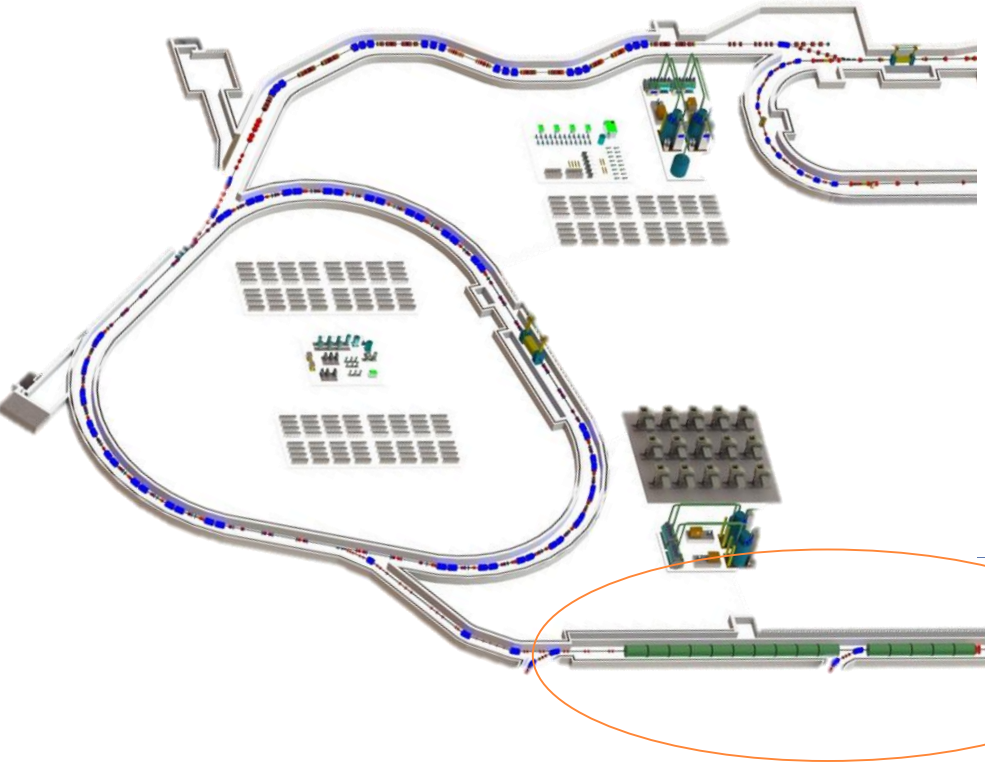
2010-2017 CAFe, IMP & IHEP, 25 MeV 180 μA cw proton beam.
Then, 30 kW (>15 MeV, >2mA) cw proton beam @ 2019 spring.

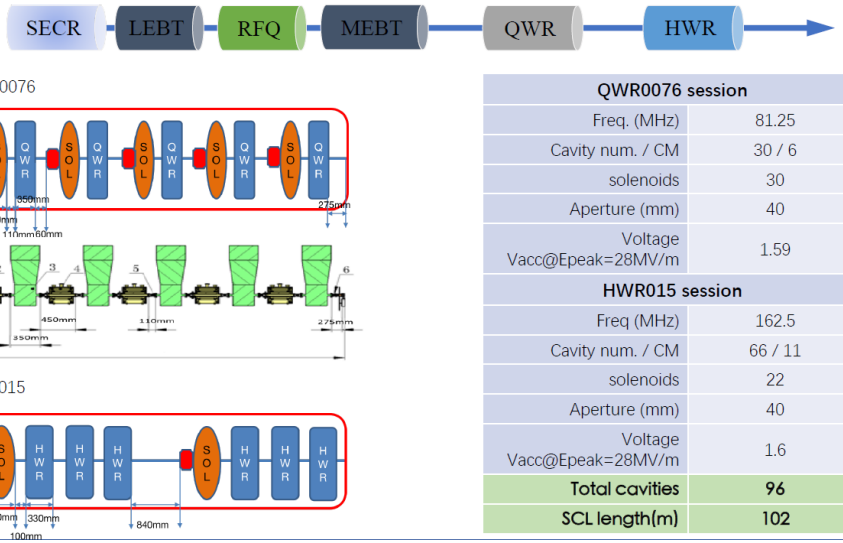
Evolution of Projects



2018-2025 SHINE, Shanghai Tech Univ., SARI, SINAP, and etc., 8 GeV CW Linac, 3 FEL undulator lines, 3 beamlines, 10 stations, PWs laser.

Evolution of Projects



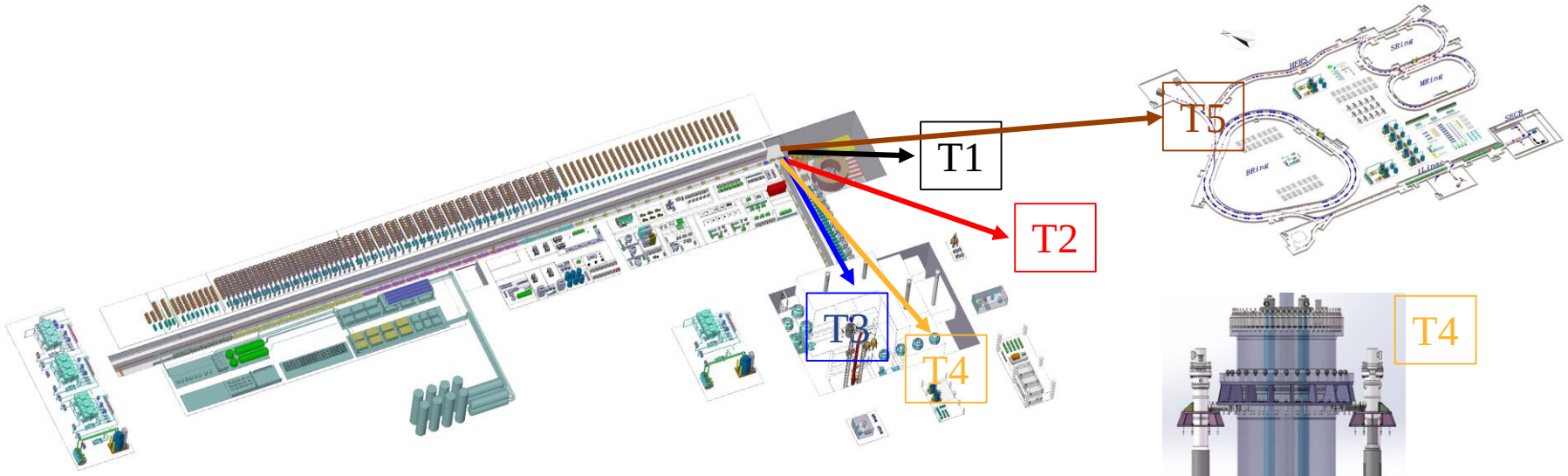


QWR0076 session	
Freq. (MHz)	81.25
Cavity num. / CM	30 / 6
solenoids	30
Aperture (mm)	40
Voltage Vacc@Epeak=28MV/m	1.59
HWR015 session	
Freq (MHz)	162.5
Cavity num. / CM	66 / 11
solenoids	22
Aperture (mm)	40
Voltage Vacc@Epeak=28MV/m	1.6
Total cavities	**96**
SCL length(m)	**102**

1990 2000 2010 2020

2018-2025 HIAF, IMP, 80 m long injector for 17~22 MeV/u($U^{35+\sim 46+}$)

Evolution of Projects

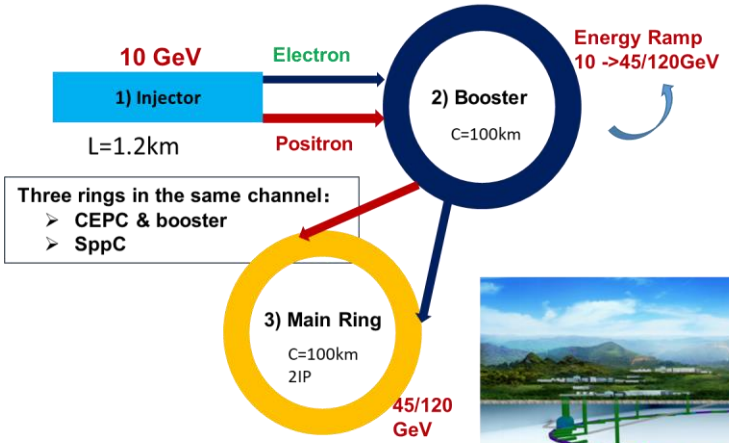


- T1: low power dump 50 kW; accelerator study; nuclear physics
- T2: liquid metal target 250 kW ~ MW; material irradiation,
- T3: granular target 100 kW ~ MW; target study
- T4: 10 MW fast reactor, LBE target, Keff ~0.97; demo of ADS
- T5: upgrade ISOL target: iLinac of HIAF is post-acc, to 100 MeV

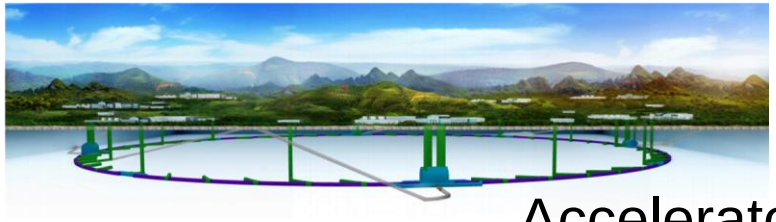
1990 2000 2010 2020

2019-2025 CiADS, IMP, 500 MeV (phase II 1.5 GeV) 10 mA CW proton Linac, 5 different terminals, strict stability requirements.

In Design Projects

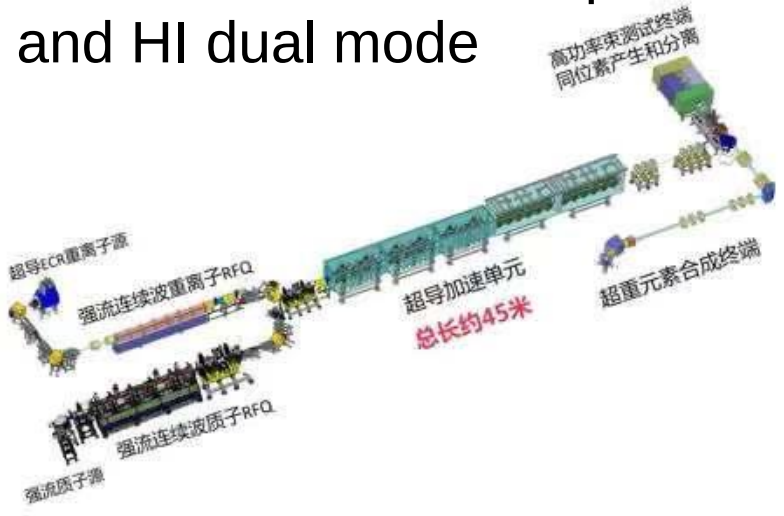


CEPC: 100 km circular collider



CSNS energy upgrade and light source

Accelerator-driven isotope factory: p and HI dual mode



Summary of Demands

Tech demands	Target projects	Comments
High Q	SHINE, HIAF, CiADS, HEPS, CEPC…	Largest 2K system (12 kW acc + 1 kW test), N-doping, large grain, EP processing,
High E_{acc}	HIAF, CiADS, CSNS, SHINE, HEPS, CEPC…	Especially important for HI injectors, neutron sources
High power & auxiliaries	CiADS, CSNS, HIAF, SHINE, Isotope…	Aiming at10 MW p beam, 20 TW e beam and high duty factor. Couplers, amplifiers, LLRF, beam loading, tuners, & etc.
TFSRF	CiADS, CSNS, HIAF, SHINE, Isotope…	Potentials for higher *T, Q, G*. Industrial applications.
Advanced fabrication	CiADS, HIAF, SHINE, CEPC	High standard mass production, high speed, low rework rate, and low cost.
Stability	CiADS	>99% availability with high beam. RAMI access, quick recovery, active compensation.
Industrialization	CiADS, Isotopes	LHe-free, hands-on operation, high stability. Low cost.

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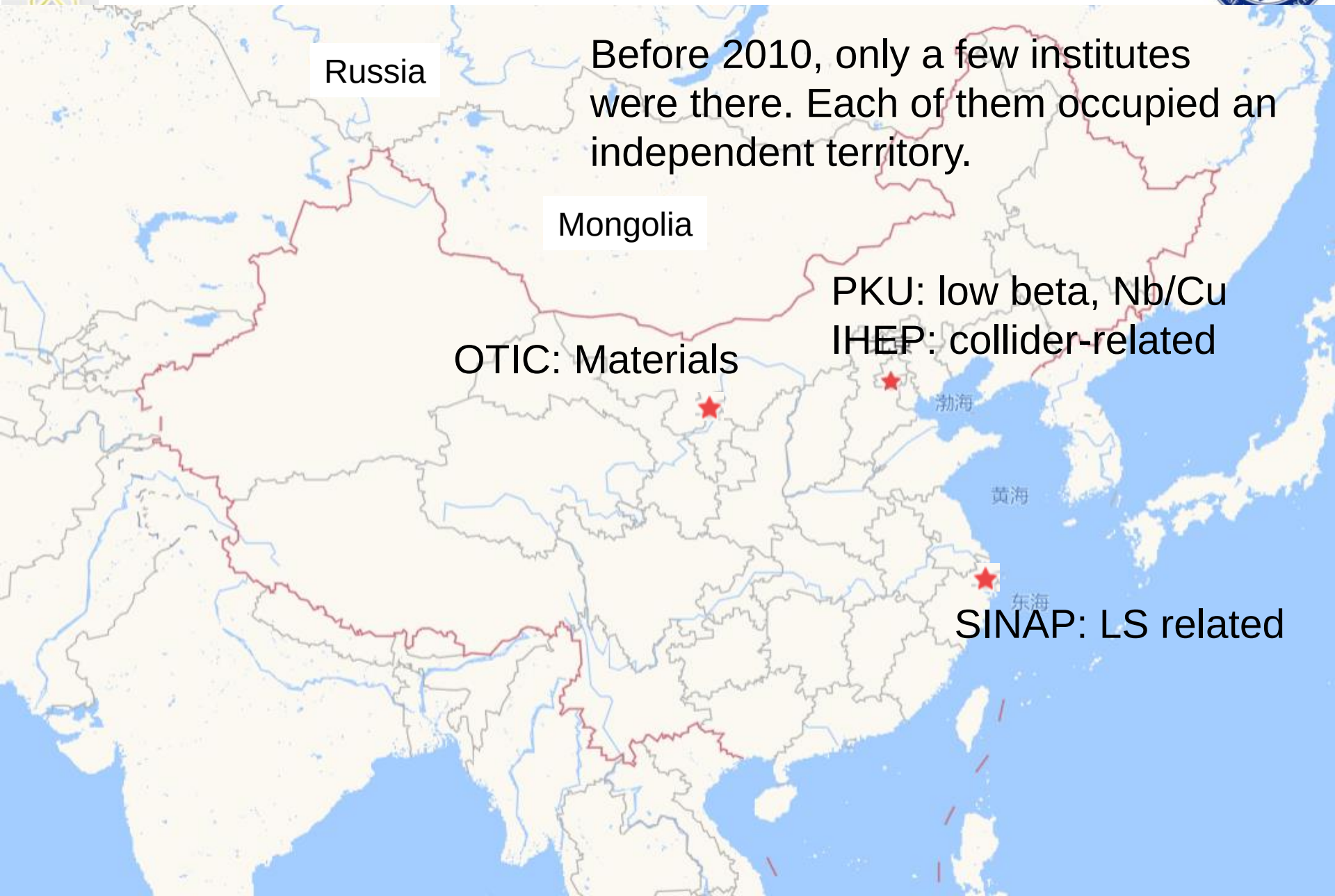
Active Research Institutes <2010



Before 2010, only a few institutes were there. Each of them occupied an independent territory.

PKU: low beta, Nb/Cu
IHEP: collider-related

OTIC: Materials

SINAP: LS related

Active Research Institutes

Active Research Institutes

Beijing Center

IHEP

- N-doping, EP
- 1.3GHz 9-cell cavities
- 650MHz 1-cell large-grain cavities
- CEPC 650 MHz Test Cryomodule
- beta=1 QWR

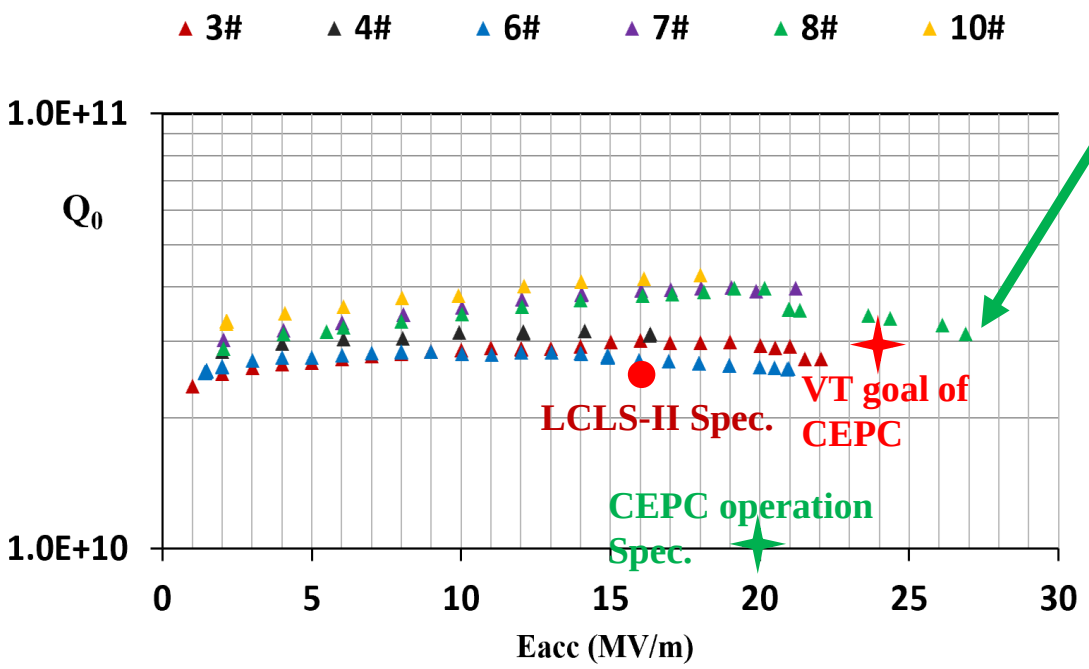
PKU

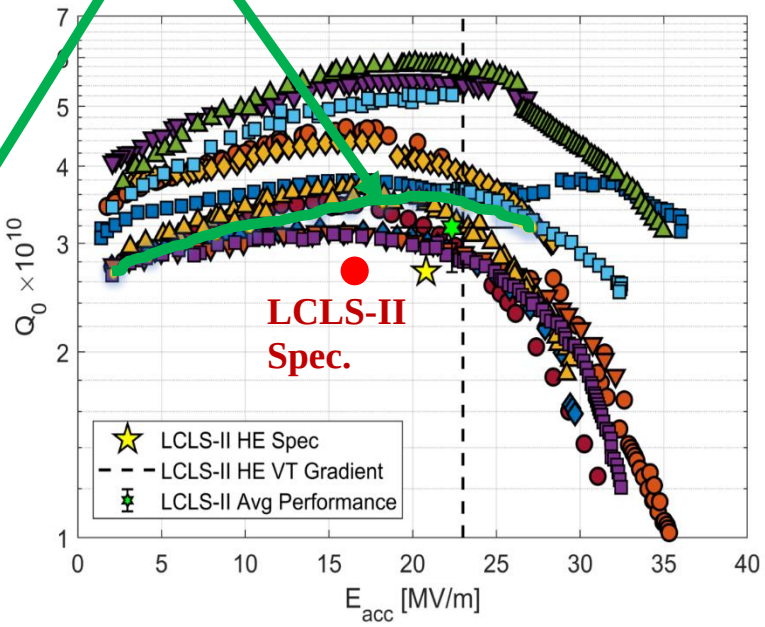
- TFSRF
- HI cavities
- Laser Annealing

- Best measurement setups
- Intense collaboration with other research institutes

N-doping of 1.3GHz 1-cell cavity

Batch production succeeds： 6 1.3GHz 1-cell cavities reached LCLS-II/SHINE design targets (2.7E10@16MV/m); Best cavity (8#) reaches 3.1E10@27MV/m





1.3 GHz 1-cell cavities for LCLS-II HE

Presented in WG1 by Chao Dong

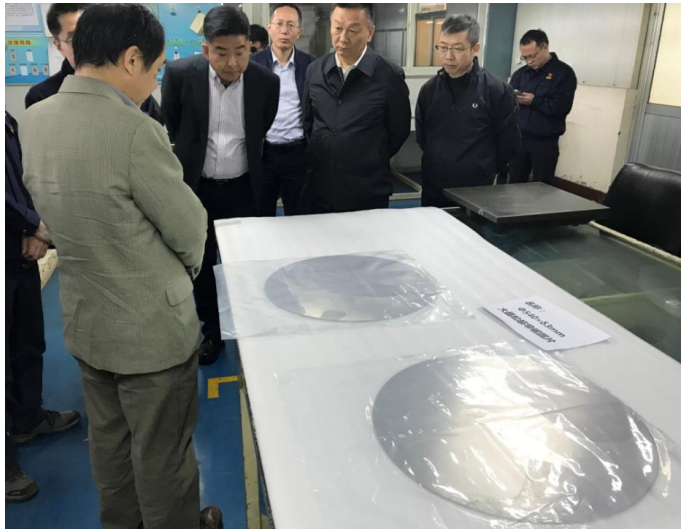
1.3 GHz 9-cell cavity

北京高能锐新科技有限责任公司
Beijing HE-Racing Technology Co., Ltd.

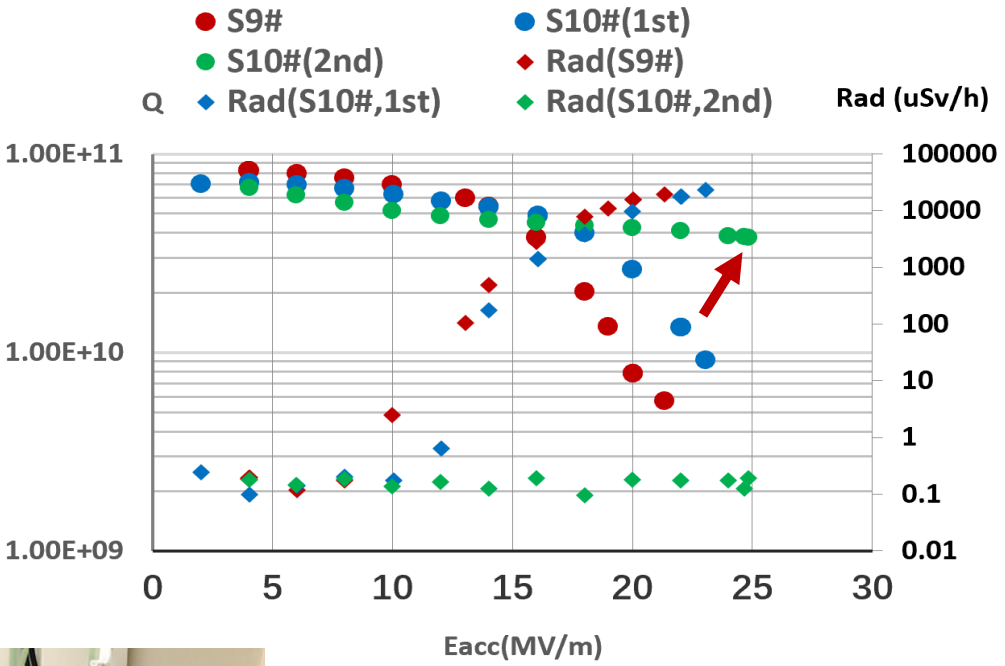
- **Eight 9-cell cavities already made for SHINE R&D. 4 cavities BCP and vertical tested.**
- **The four 1.3 GHz 9-cell cavities with jacket passed SHINE's phase-1 test, being the first batch of submission.**




Large Grain 650 MHz Cavity



Large grain Nb sheets made by OTIC



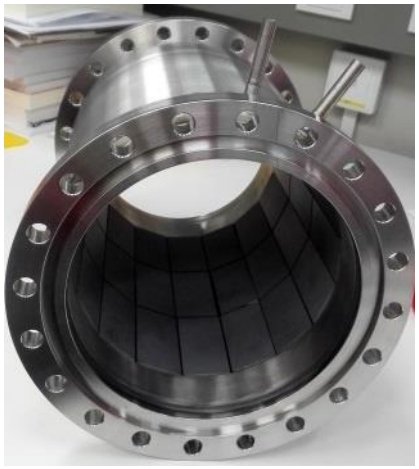
Half cell after deep-drawing

BCP

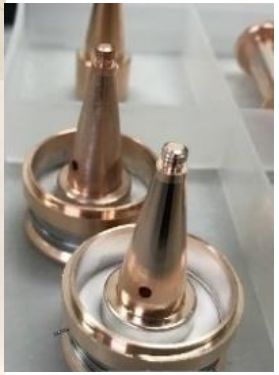
Wasn't so successful. Inner surface quality confined.

650 MHz Test Cryomodule for CEPC

Cryomodule with two 650 MHz 2-cell cavities: under development, assemble in 2020.

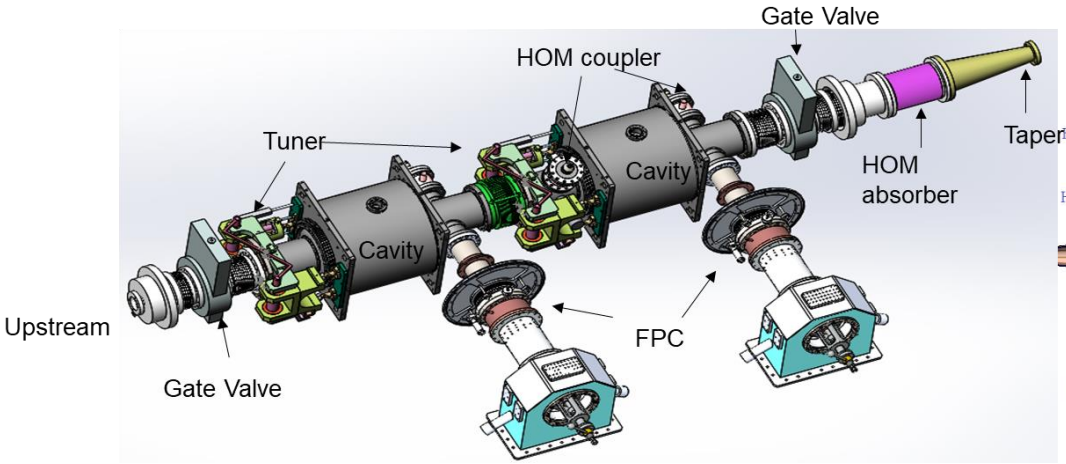


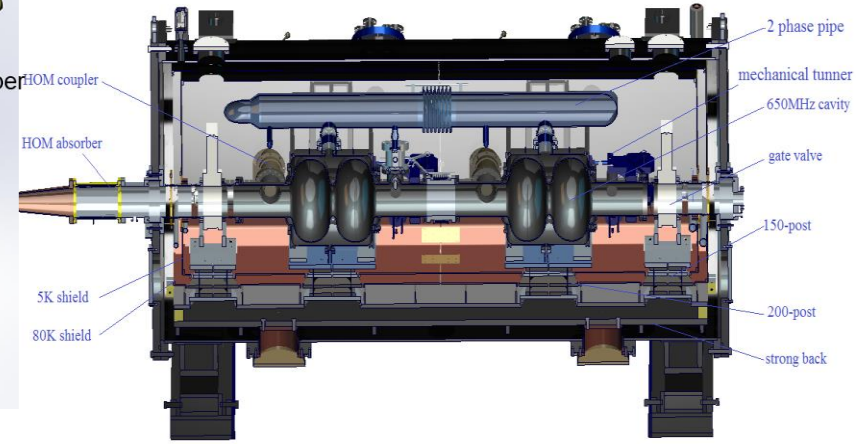
SiC/AlN HOM absorber



FPC

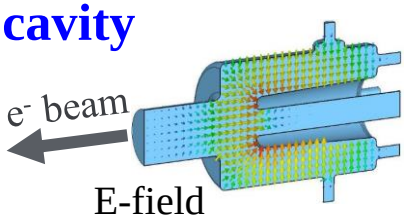
CM ready for deliver





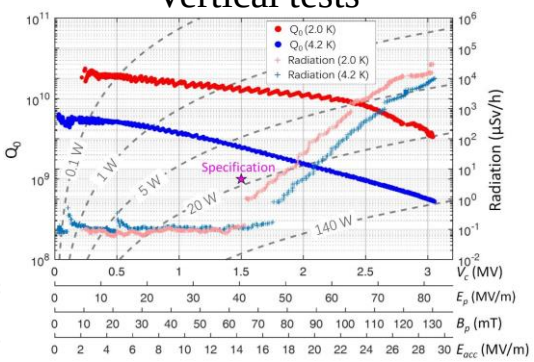
166.6 MHz quarter-wave β=1 SRF cavity

Proof-of-Principle cavity

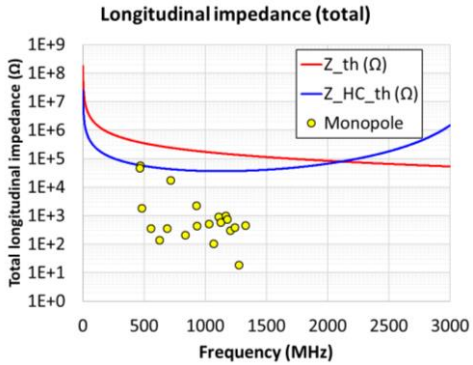


Parameter	Value	Unit
Frequency (f_0)	166.6	MHz
Frequency of nearest mode	433	MHz
$\lambda/4$ of π mode	449.9	mm
Cavity length (main body)	530	mm
Cavity diameter (no ports)	397	mm
Aperture diameter (small side)	80	mm
Operating temperature	4.2	K
Accelerating voltage (V_c)	1.5	MV
Accelerating gradient (E_{acc})	12.5	MV/m
Peak surface electric field (E_p)	40.1	MV/m
Peak surface magnetic field (B_p)	63.9	mT
B_p/E_p	1.59	mT/(MV/m)
Stored energy (U)	15.8	J
R/Q ($=\|V_c\|^2/\omega U$)	136.0	Ω
Geometry factor ($G = R_s \cdot Q_0$)	54.5	Ω

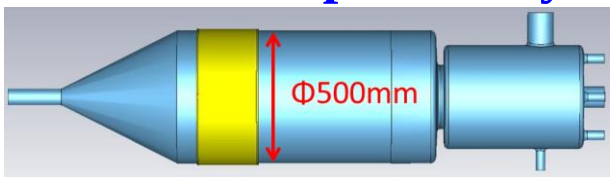
Vertical tests

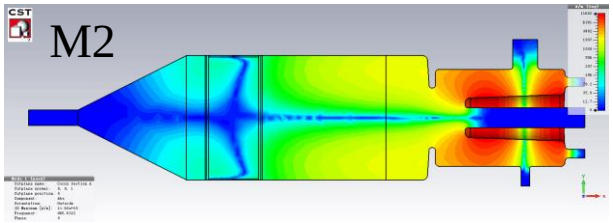


Coupled bunch instabilities

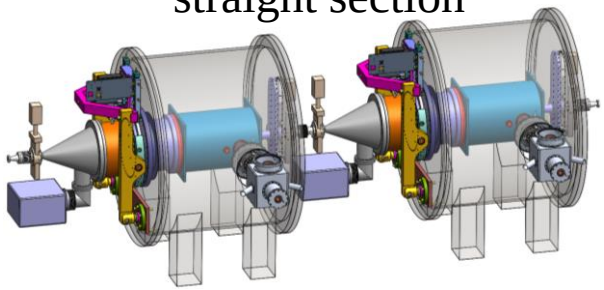


HOM-damped cavity





Two cavities in one 6m straight section

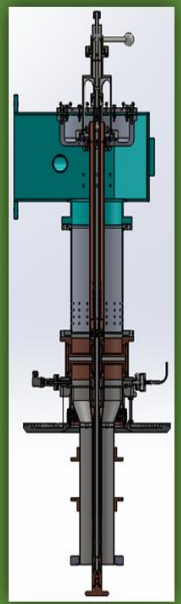


[1] P. Zhang et al., Rev. Sci. Instr. **90** (2019) 084705.
[2] X.Y. Zhang and P. Zhang et al., NIM-A **947** (2019) 162770.

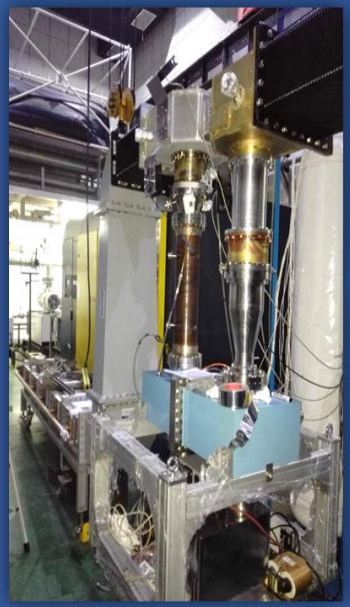
Coupler gallery (BEPCII, CADS, HEPS-TF)

BEPCII 500MHz

CEPC 650MHz



CADS 650MHz

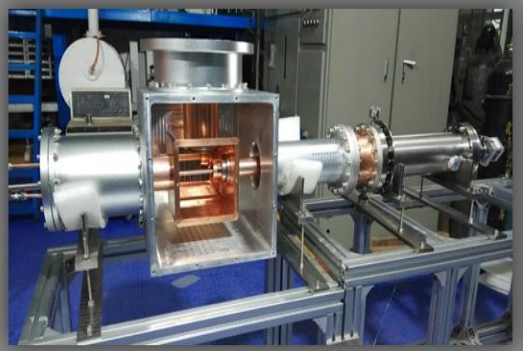


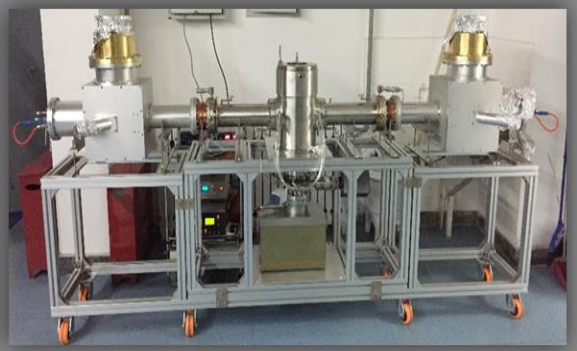
CADS 325MHz (Spoke, RFQ)

CADS 162.5MHz

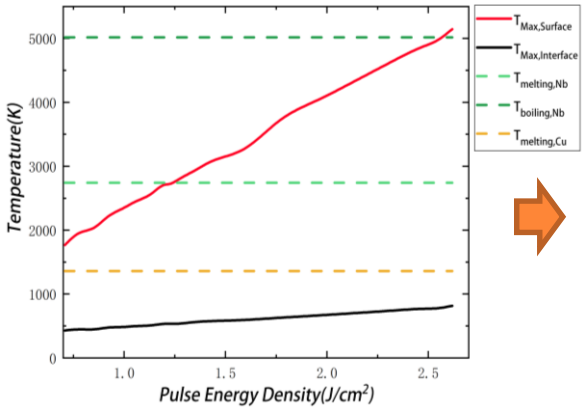
IHEP RF group has over one decade of experience on design, fabrication and power testing of FPCs and their beam operations.

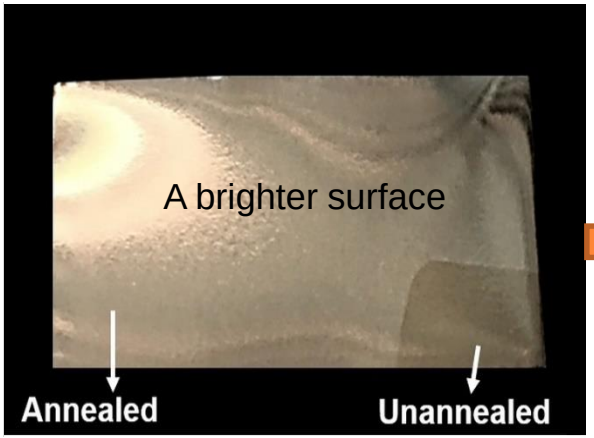
HEPS-TF 166.6MHz

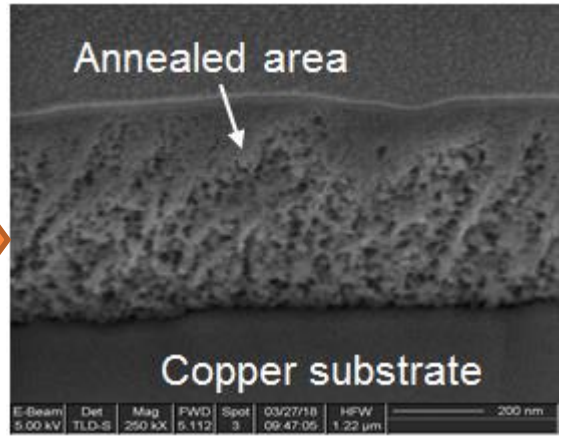


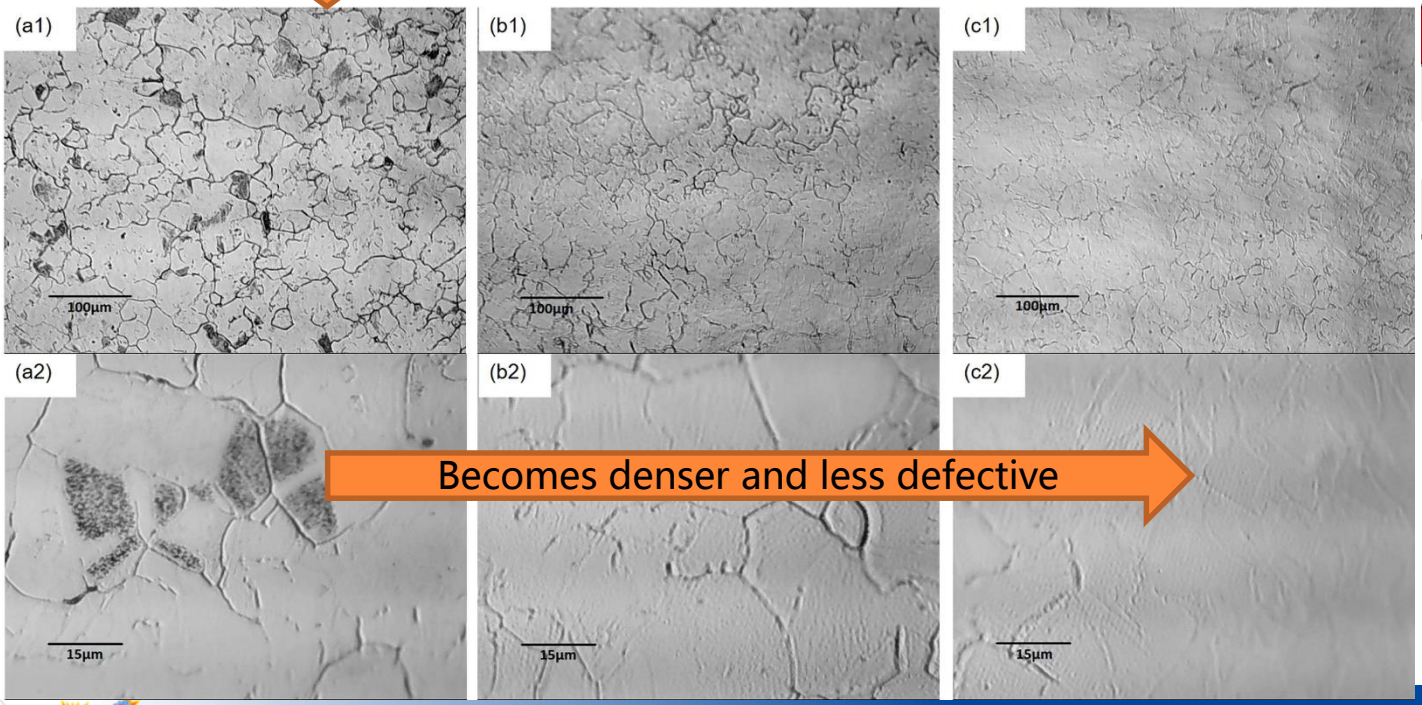


Laser Annealing of Nb/Cu Film-PKU

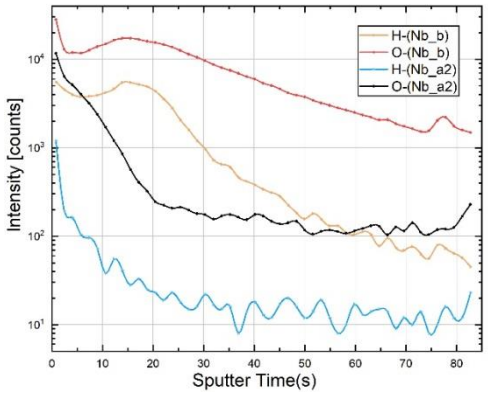








Ra (Reduced by 74%!)	
Nb/Cu_b	$19.60 \pm 0.36nm$
Nb/Cu_a2	$9.71 \pm 0.85nm$
Nb/Cu_a1	$4.97 \pm 0.29nm$



Reduction of both H and O

Northwest Center

IMP

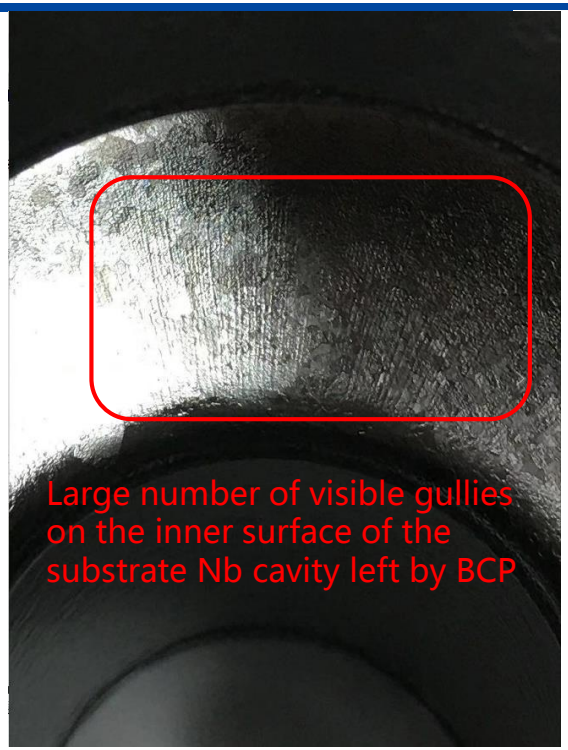
- Nb_3Sn/Nb
- Plasma processing
- Pondermotives
- Copper based TFSRF
- Stable high beam machine
- Automatic clean room
- Industrialized SRF

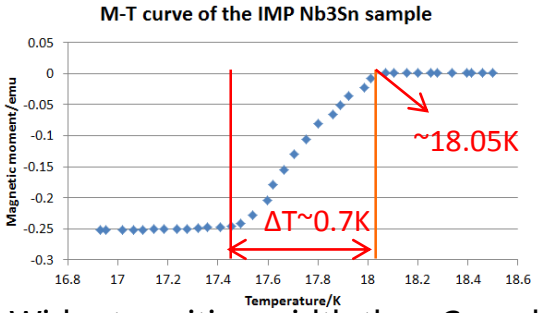
NIN

- SC magnets and solenoids
- Nb_3Sn/Cu

- Aiming at further industrialization of SRF.
- New 2K VT dewars ready.

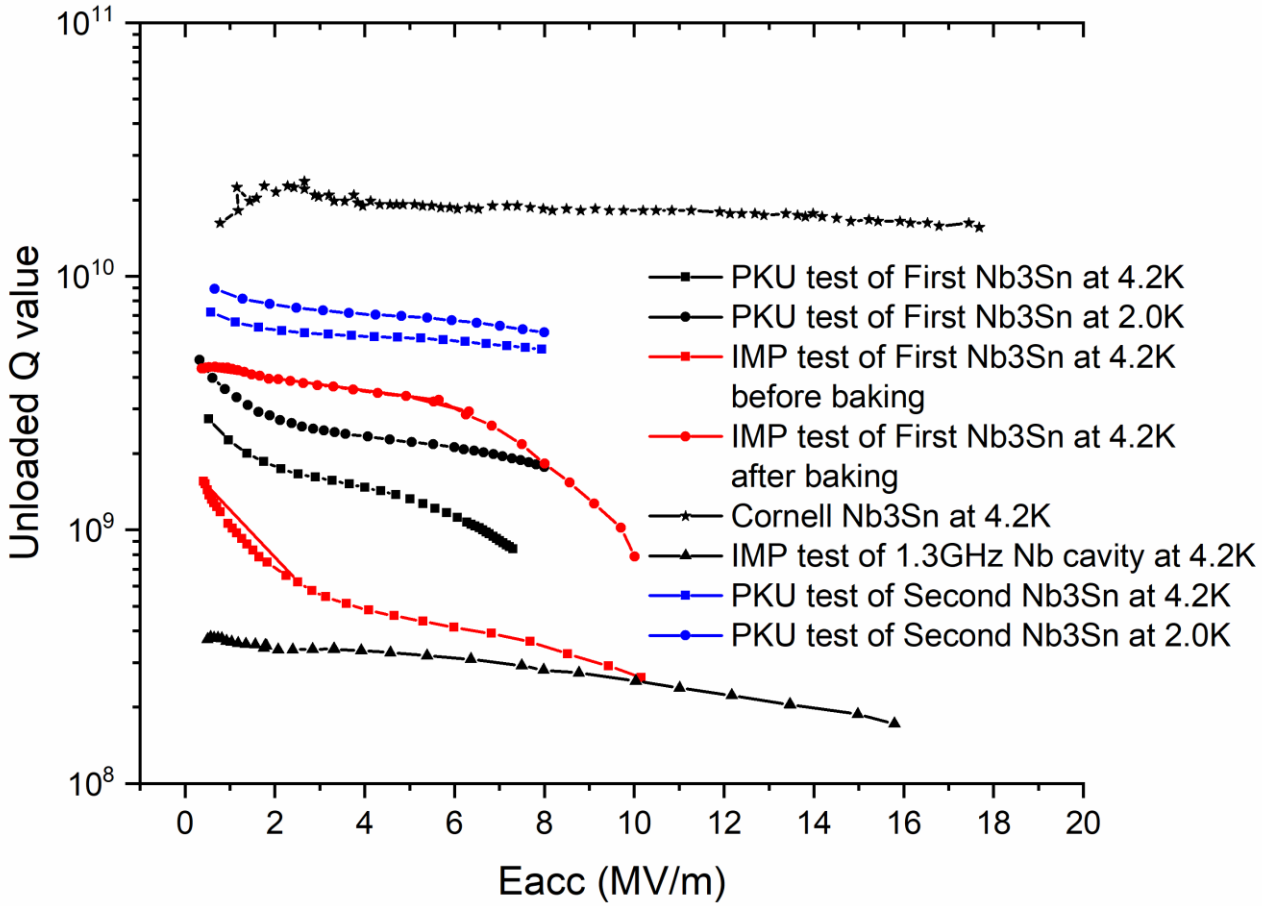
Development of Nb_3Sn cavity at IMP





Wider transition width than Cornell (~0.12K)

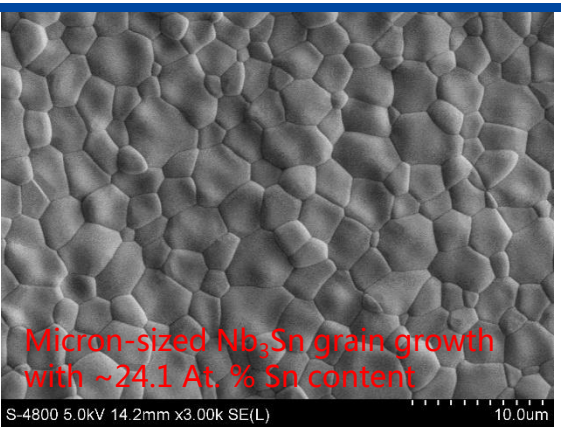
Latest optimization of the coating process

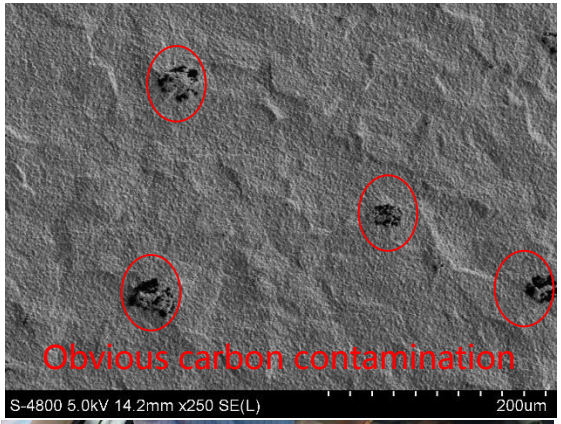


1. Obvious improvement: Q_0~7.6e9@4.2K, quenched at 8MV/m;
2. **Contamination and defects** were suspected to the lower Q_0 and quench field.

Reported on SRF2019

Upgradation of the deposition system



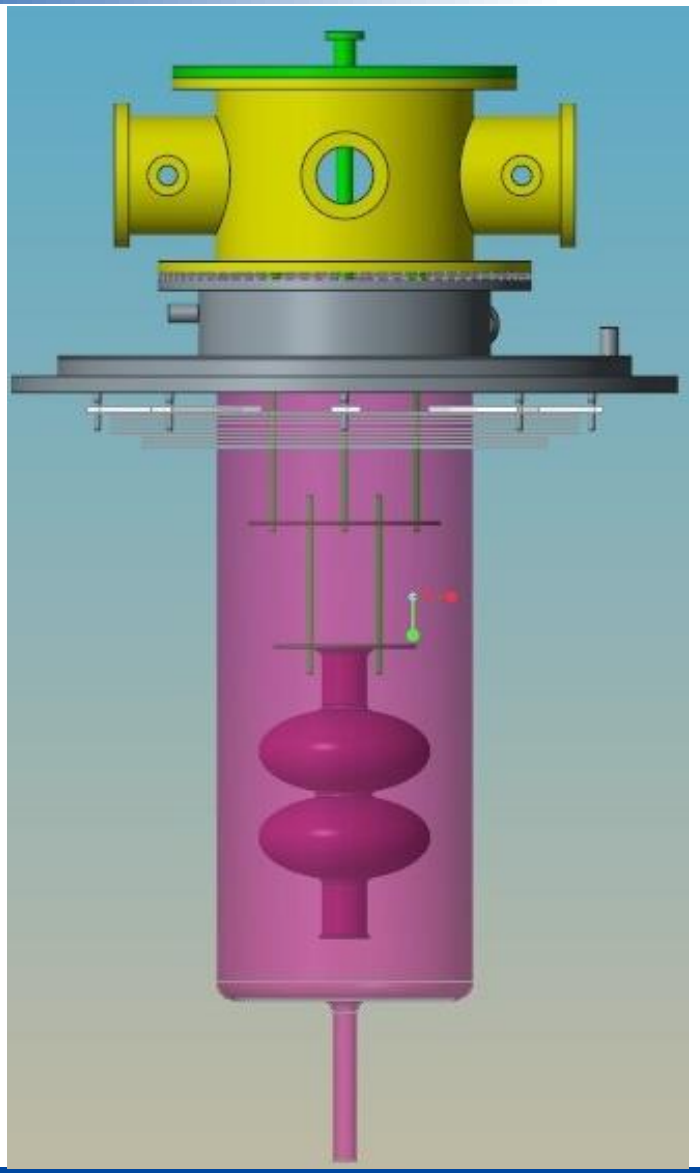


Minimization of the contamination

Vacuum-isolated Nb chamber was biult

Shortened distance between Sn and cavity

Any part in the hot zone were made by W or Nb



Air exposure of HWR015 cavity

➢ Air exposure and cryogenic test at 4K

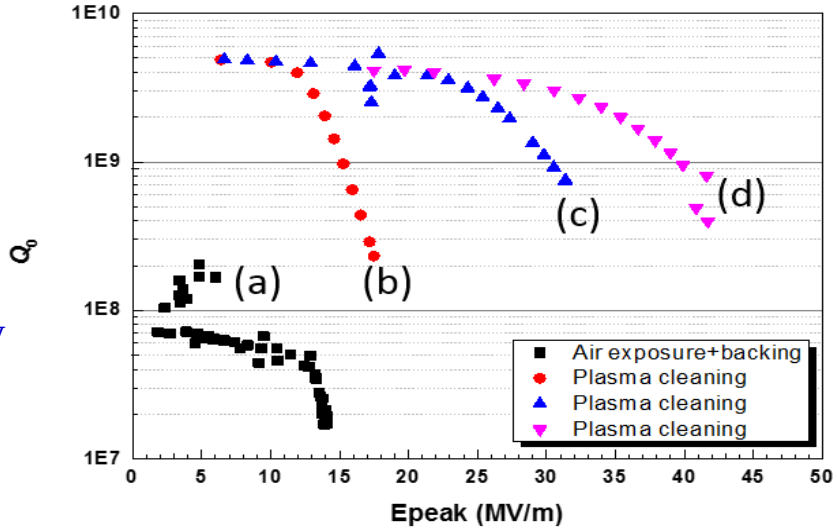
- Room temperature, Vacuum to 9.4mbar.
- Test at 4K: 8 hours RF pulse conditioning, field can not be established.
- Warm up to RT and 120^{O}C×58hours baking.
- Test at 4K(a): 6 hours RF pulse conditioning, limited by MP.

➢ Ar/O2(1-3%) plasma cleaning

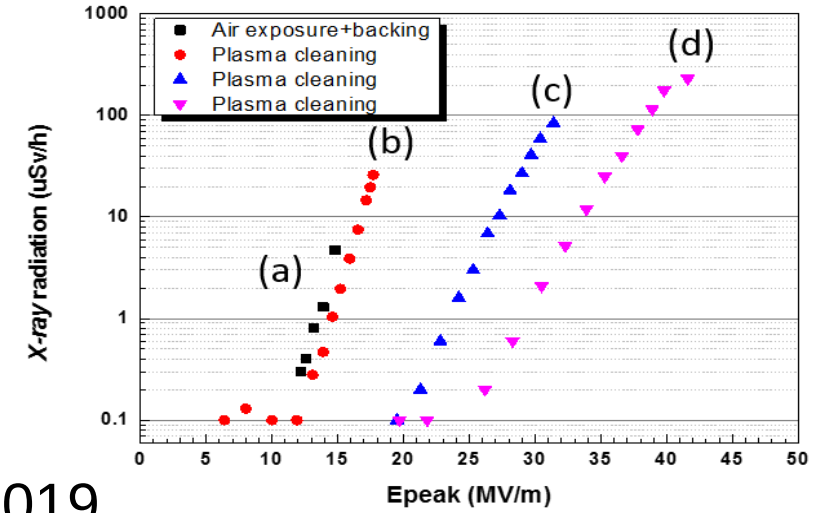
- Parameters: Ar/O2(1-3%), pressure:0.5-0.8Pa, pulse on/off: (10-30s)/(2-5mins), Power:60-80W), active cleaning time:150mins.

➢ Cryogenic test at 4K

- Curve (b): Q0 recovered at low field(5E9), encounter MP barrier
- Curve(c): took after 5 mins RF conditioning, low field MP disappeared, and MP appeared at 17MV/m.
- Curve(d): RF conditioning at 31.5MV/m, quench field improved to 41.8MV/m



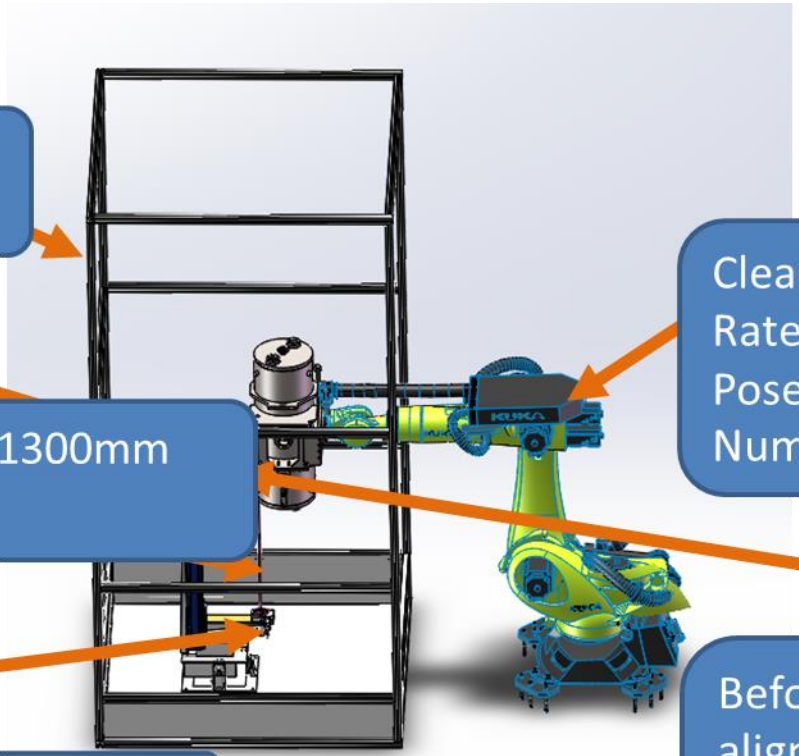
Q0 VS Epeak



X-ray VS Epeak

Reported on SRF2019

Cleanroom automation



Water shelter frame

Covered by Anti-static plastic

Linear motion system

Stroke length, maximum: 1300mm
Ingress protection: IP67

Length: 1400mm
Diameter: 12mm

feedthrough

Maximum water pressure: >150bar

Cleanroom robot

Cleanliness: ISO4 & ISO5
Rated payload: 210 kg
Pose repeatability: ±0.06mm
Number of axes: 6

Alignment system

Before every process, alignment system will check the status of cavity which could avoid cavity damage by spray wand.

Reported on WG4 by Tan

Yangtze Delta Center

SARI

- N-doping
- 1.3 GHz cavity mass production
- High P FPC
- Cryogenic system
- Auxiliaries
- Clean assembly

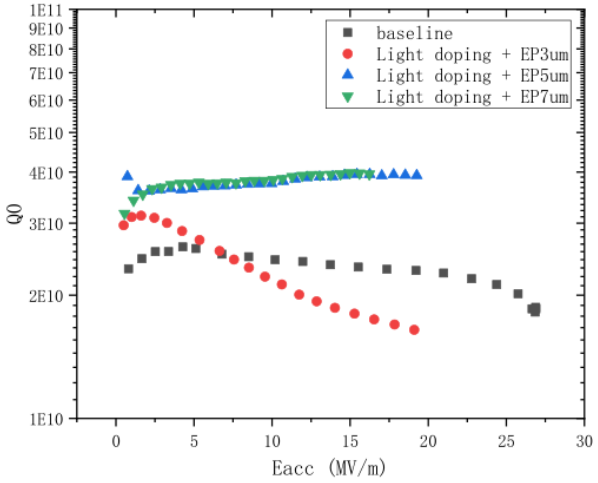
CNITECH

- Ceramics
- Field emission

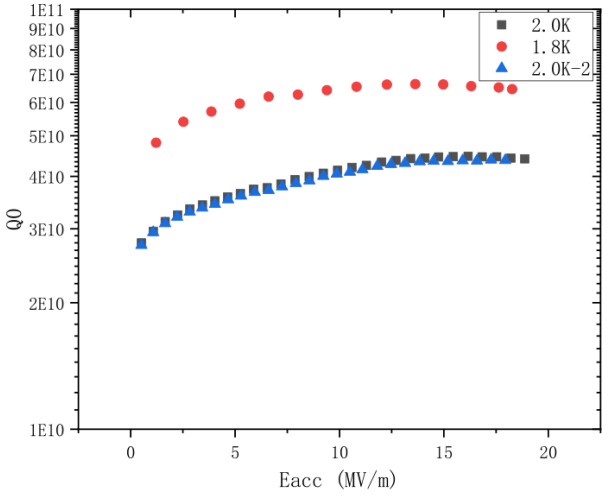
Wuxi Chuangxin

- Surface Processing

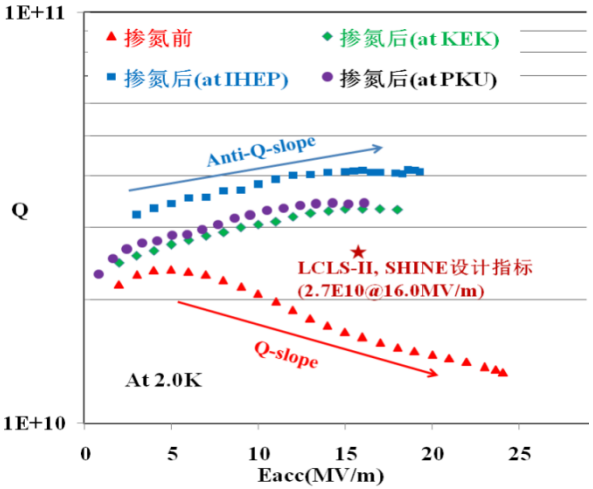
Progress of nitrogen doping treatment



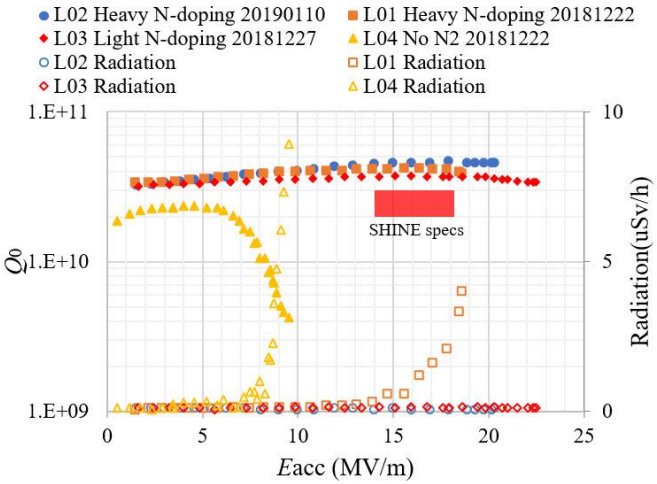
PKU large grain Nb cavity: Eacc=19.3MV/m, Q0~3.9e10@16MV/m



PKU fine grain Nb cavity: Eacc=18.9MV/m, Q0~4.4e10@16MV/m



IHEP fine grain Nb cavity: Eacc~19.4MV/m, Q0>4.0e10@16MV/m



SARI large grain Nb cavity: Eacc=22.5MV/m, Q0>3.0e10@16MV/m

- RF performance better than the SHINE speculation has been achieved;
- Further optimization of EP&N-doping for the repeatability verification and Eacc enhancement.

1.3 GHz Cavity

- 3 teams develop the cavity aiming at high Q in parallel.
- 4 dressed cavities were received from G1.
- 3 bare cavities are fabricated and under testing at G2 and G3.
- High Q value is observed in single cell cavity with EP and doping.

G3 SARI

1 bare cavity (FG):
Under surface treatment and VT

G1

4 dressed cavities (FG):
Q_0~2×10^{10}@16MV/m,
E_{max}~25MV/m

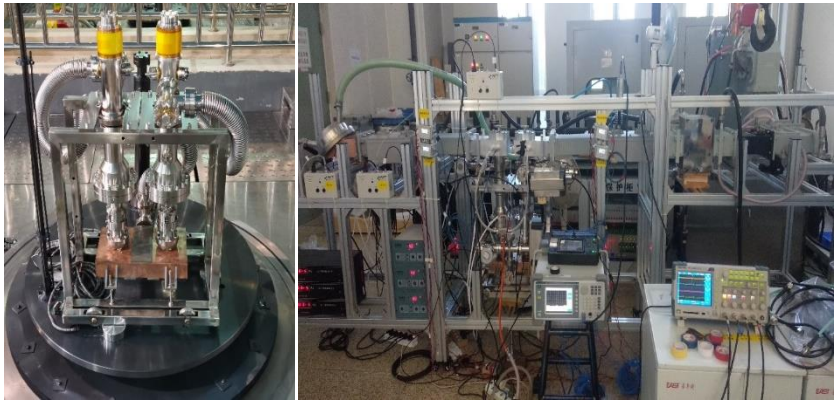
G2 OSTEC

2 bare cavities(LG):
Q_0~1.8×10^{10}@16MV/m, E_{max}~26MV/m

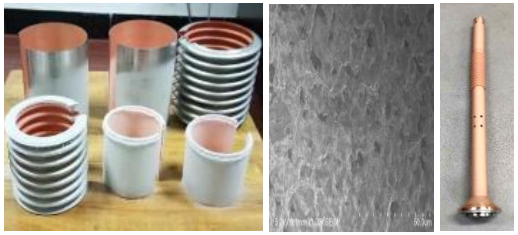
Single-cell cavities, (LG, N-doping):
L02: Q_0=5.6E+10@16MV/m,
E_{max}=19.6MV/m
L03: Q_0=3.8E+10@16MV/m,
E_{max}=22.5MV/m

1.3 GHz FPC

- 3 teams develop the FPC in parallel.
- R&D of key technologies are carried out.
- 8 FPCs are fabricated and 6 of them passed the RF conditioning.
- Cold test is under preparation.

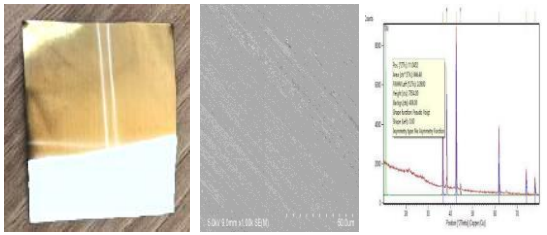


Prototype #3 in conditioning



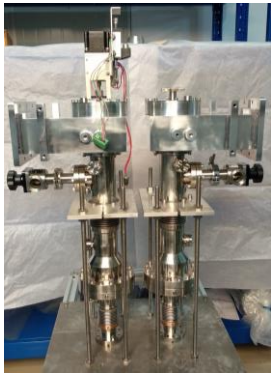
Cu coating

Brazing



TiN plating

EBW



Prototype #1

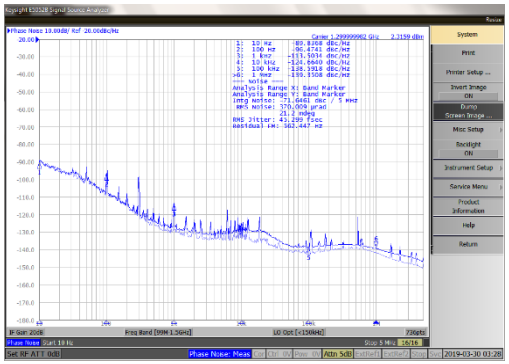
Prototype #2

SSA

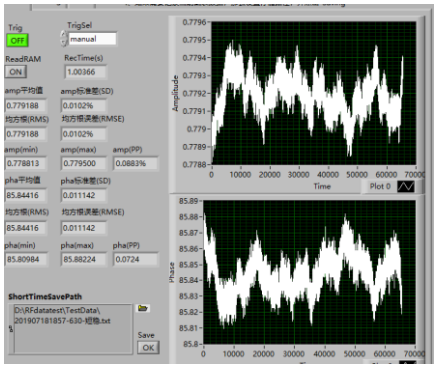
- 4 manufactures develop the SSA in parallel
- 3 SSA prototypes are developed and reach the specification.
- Long term conditioning is under performed at SARI.

	Requirement	Acceptance test result
Frequency	1.3GHz	1.3GHz
Delay of small signal	<300ns	44ns
1 dB compression	5.2kW @0dBm	5.5kW
Bandwidth(1dB)	1MHz	2MHz@0.1dB
Phase noise	80dBc/Hz(10Hz offset @1.3GHz)	89dBc/Hz
Amplitude stability	0.1% @ 1 second	<0.1%
Phase stability	0.1° @ 1 second	<0.1°
Spur	<-70dBc	<-70dBc
Noise	<10 dB	2dB (90-88)
Harmonic	<-30 dBc	-38 dBc@5th
Efficiency	>40% (at 5.2kW)	41%

Chengdu 630



Phase noise： 89.8dBc/Hz @offset 10Hz/1.3GHz 45fs(10Hz to 5MHz)



Amplitude: 0.088%, Phase: 0.072

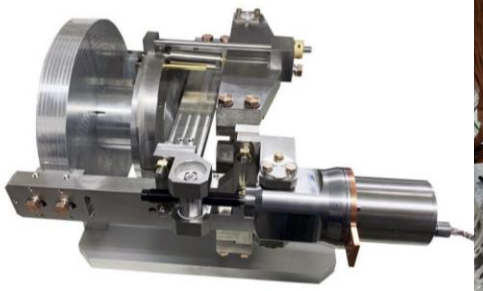
Wattsine

BBEF

Auxiliaries

Tuner

- First prototype fabrication.
- Warm test of the tuner performance isperformed.
- Cold test is ongoing.

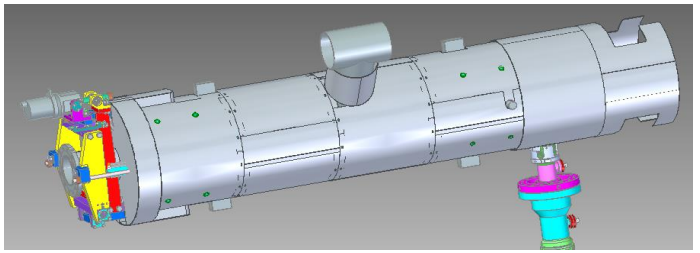


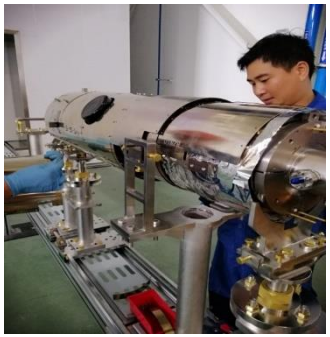
Prototype

Cold test

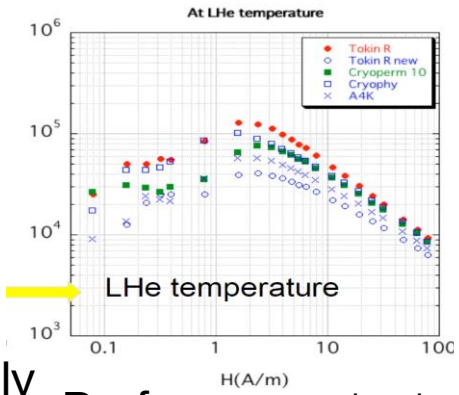
Magnetic Shielding

- Material R&D。
- Material performance test at room and LHe temperature。
- First shielding structure fabrication and assembly test.





Prototype assembly

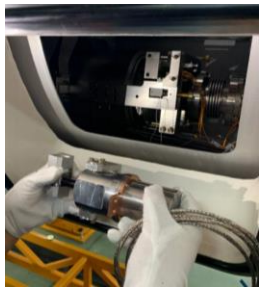


Performance test

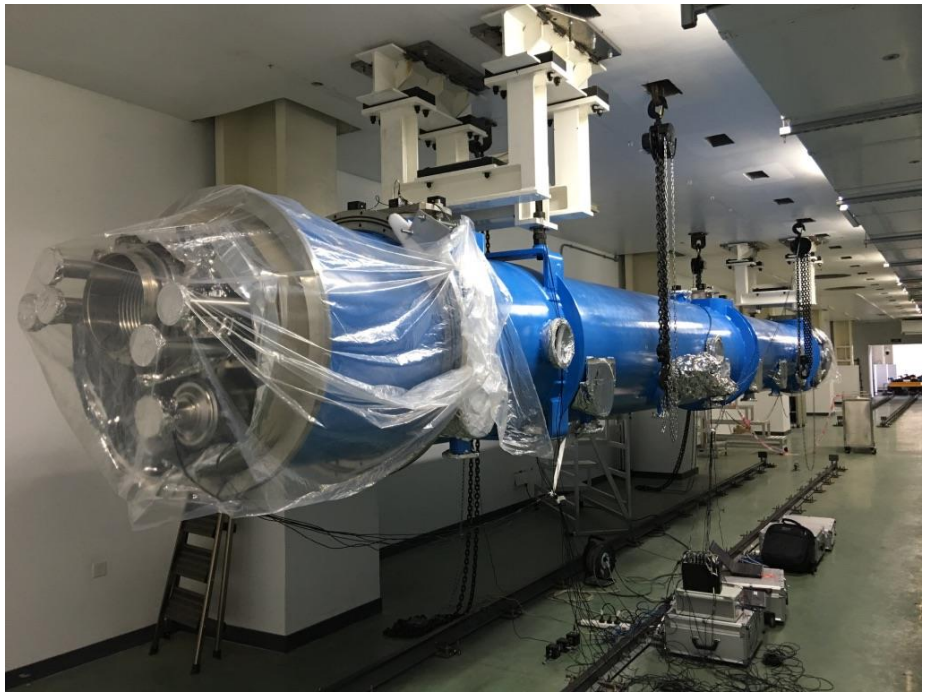
Assembly Test

- Check and confirm the CM general design
- Check the components design and fabrication
- Check and confirm the tools and procedure
- Train the assembly team





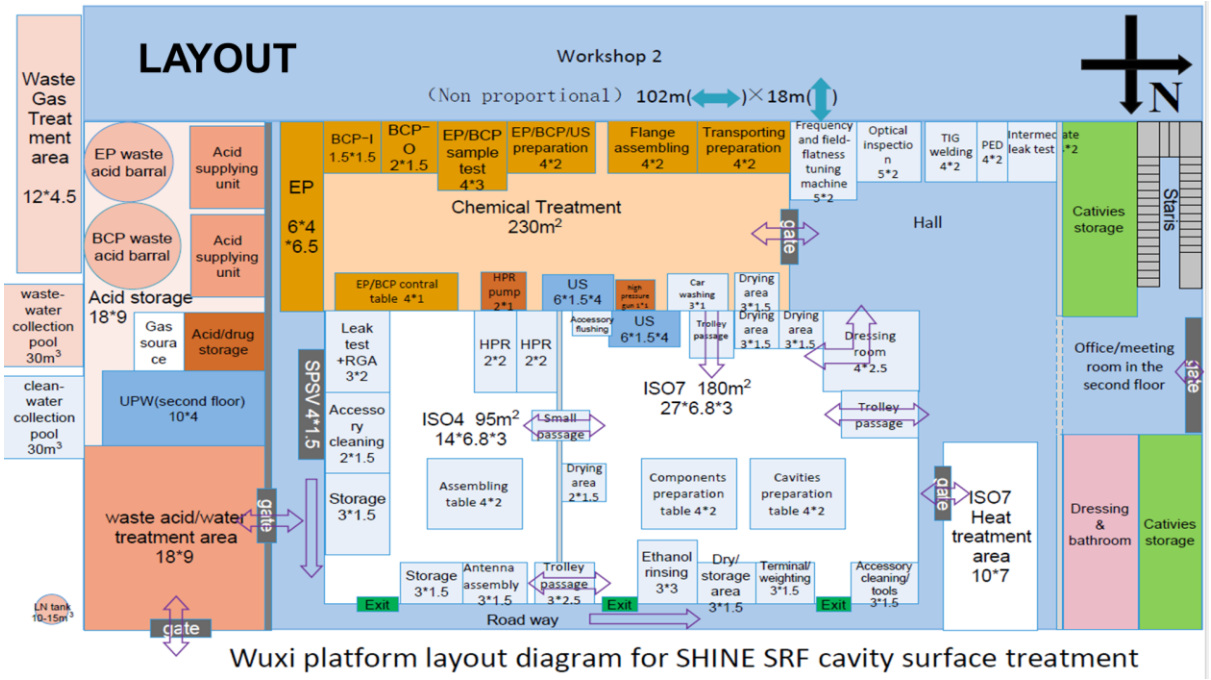


Mechanical performance test

Surface-treatment Platform

- A surface-treatment platform is under construction in Wuxi city.
- Aiming at dealing with all the procedures after cavity fabrication, and before vertical test.
- Main facilities: EP, BCP, UPW, HPR, US, Vacuum furnaces, Clean rooms, Optical inspector, Tuning machine, Waste dealing facility



Wuxi platform layout diagram for SHINE SRF cavity surface treatment

Building transformation

Vacuum furnace

Outlines

1. Demands: SRF projects in China
2. Supplies: SRF tech. researches in China
3. Supply-and-demand
4. Prospects

Unbalanced Demand and Supply

In the last years, situation was challenging.

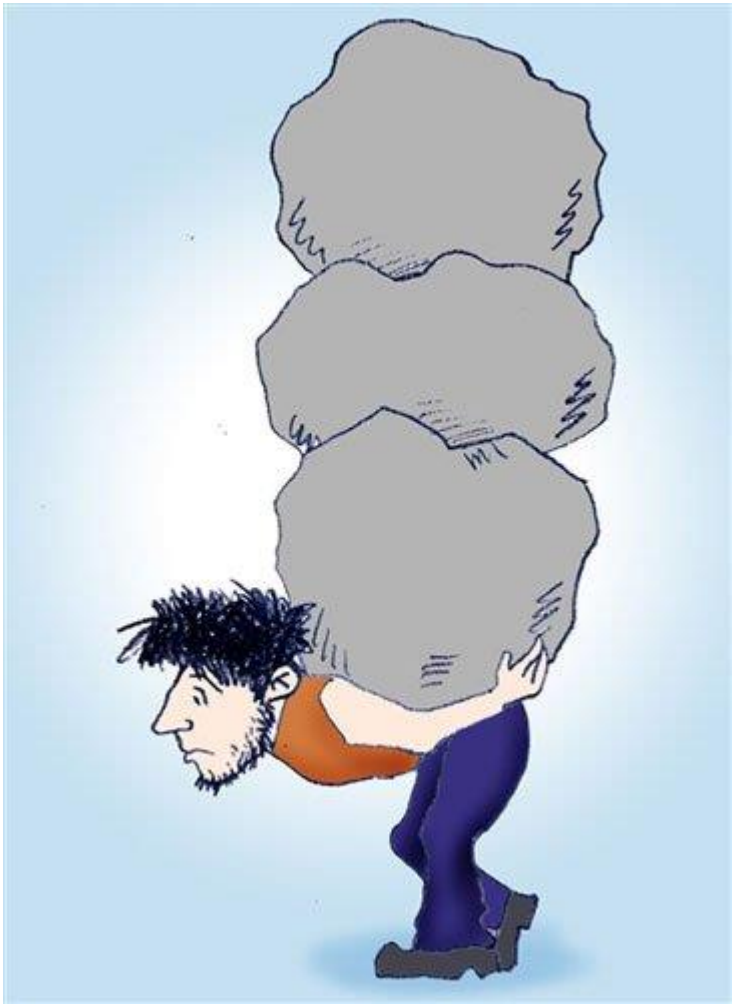
Total major projects in 2019: 4+3
Total number of SRF researchers in China:

~100

Targeted directions:

- High Q/G
- TFSRF
- Stability
- Novel manufacturing
- Engineering
- Project QC

and etc.



Overloaded China SRF community

How to solve the problem?

1. Optimize what we have:

in Sept. 2019, first China SRF workshop was held in Dalian, China. ~100 participants, ~20 institutes and companies. Topics: What are the most urgent tasks from all demand ends?

High-*Q* & stability!

How to solve the problem?

2. Expand the party:

Introducing more experts for specific topics

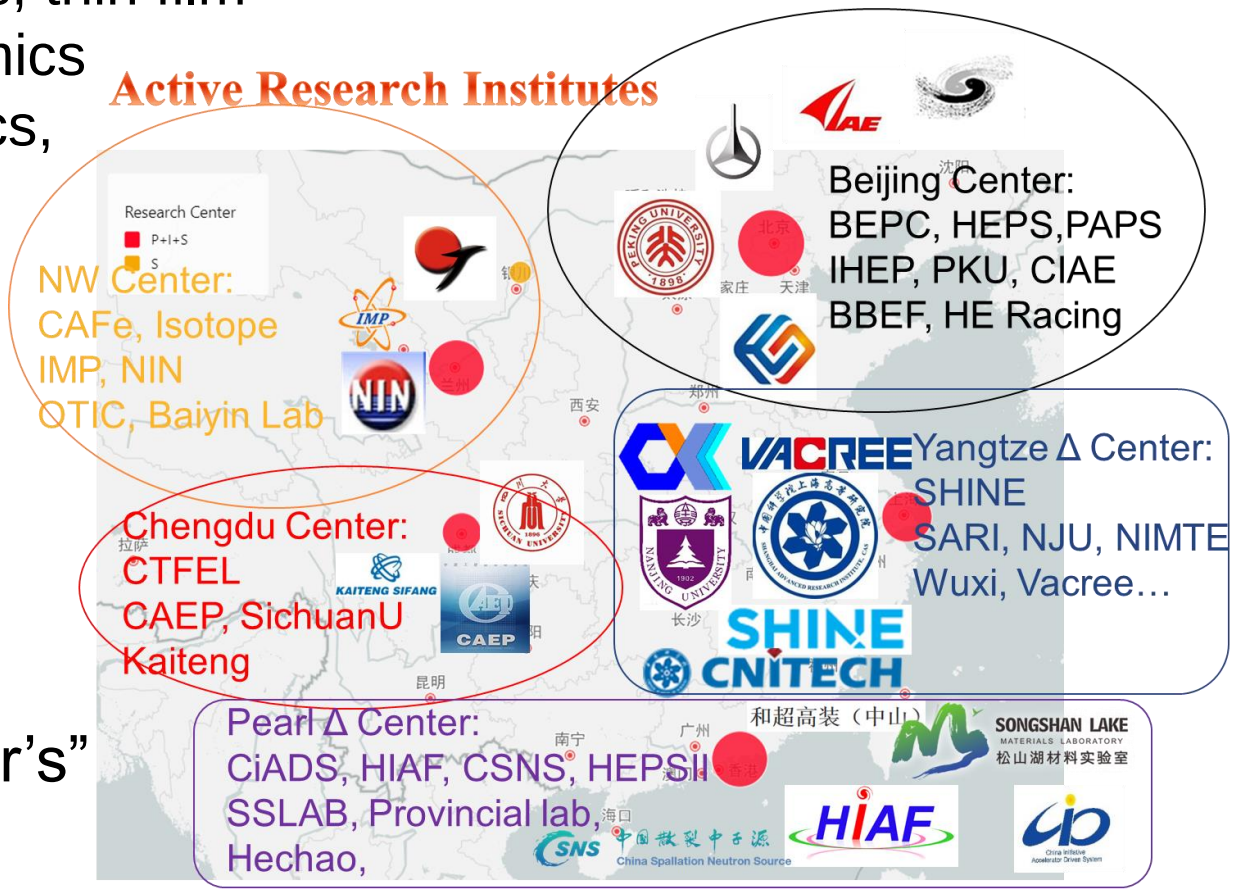
IOP: new materials, thin film

NJU: vortex dynamics

LZU: SC mechanics,

And etc.

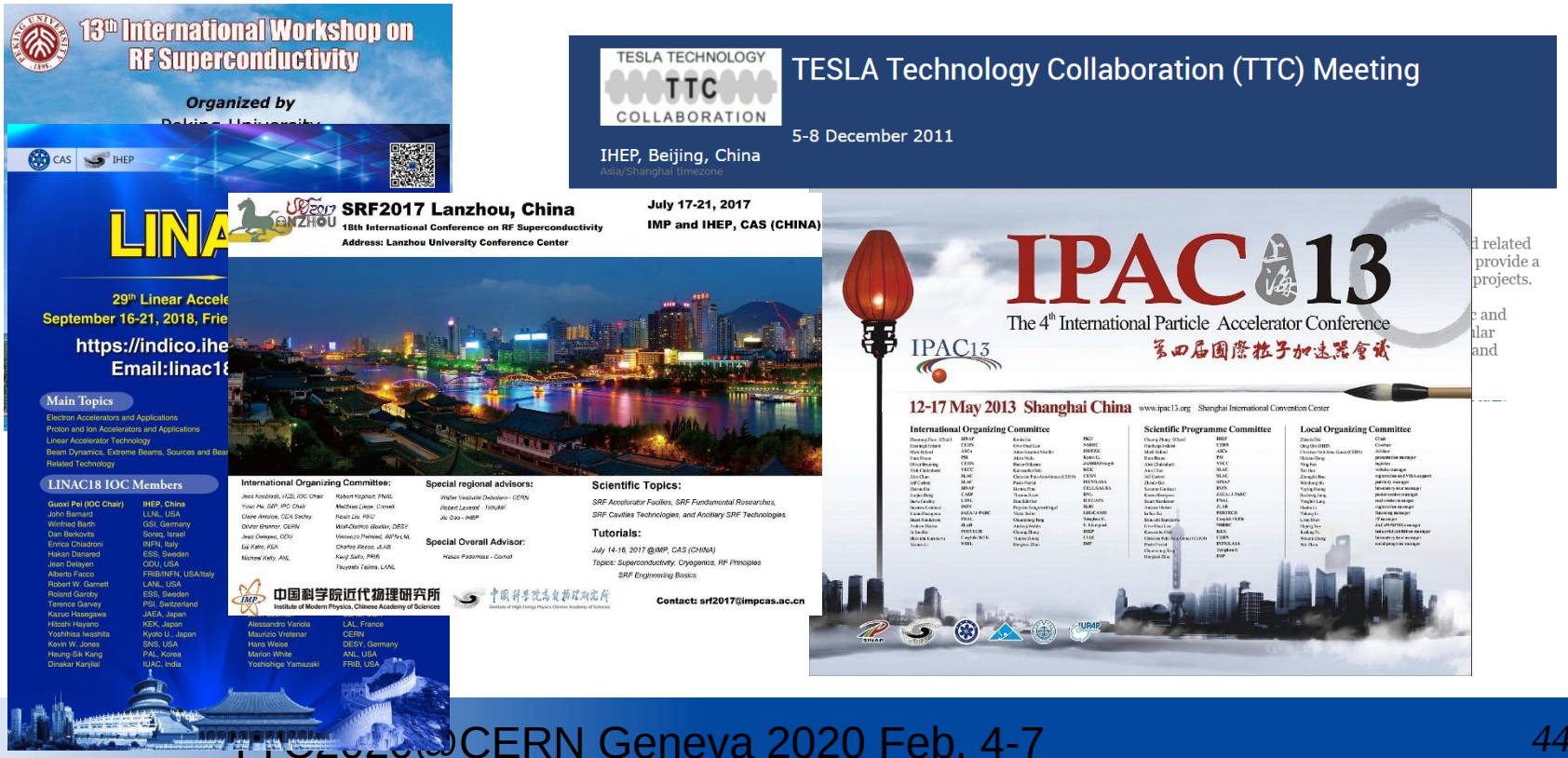
“Give back to project what is project's, to research what is research's, and to vendor what is vendor’s”



How to solve the problem?

3. Open to collaboration:

Sufficient International collaboration will facilitate technical communication, help people grow up faster, and learn lessons and experience from the past better.



Outlines

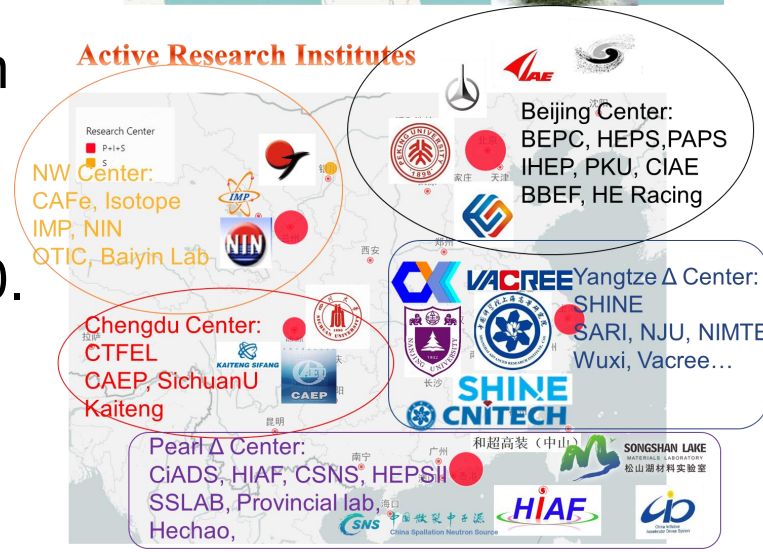
1. Demands: SRF projects in China
2. Supplies: SRF tech. researches in China
3. Supply-and-demand
4. Prospects

Prospects

China SRF community is growing: maybe the fastest for now.
3 facilities in operation, 4 projects are running, 3 in proposals, numerous in pre-research.

Outsider-> learner -> active participant in the SRF community
1 research group in 2000, 4 groups in 2010, and in almost all directions in 2020.

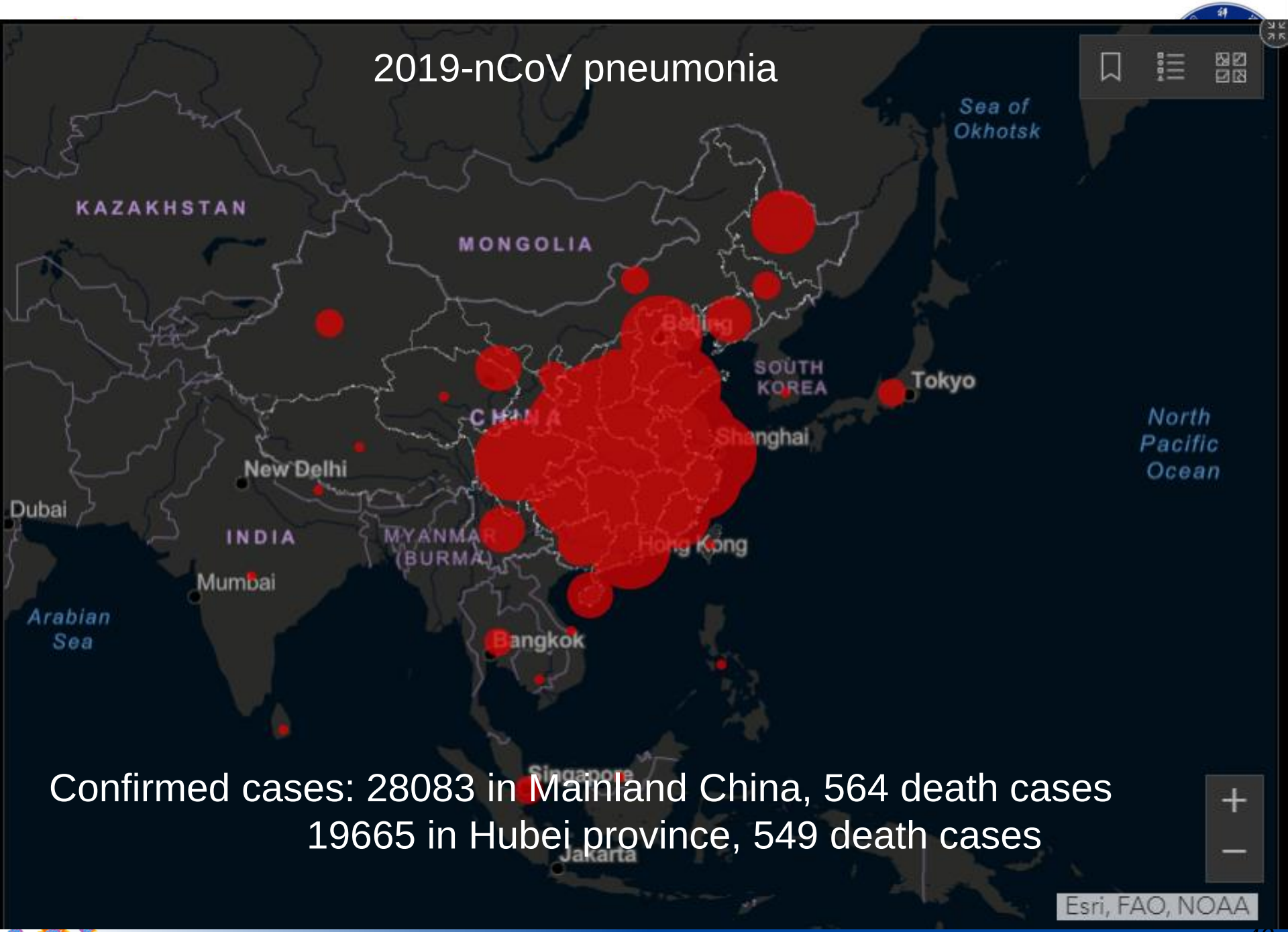
We expect a bright future for China SRF researches!



Thanks

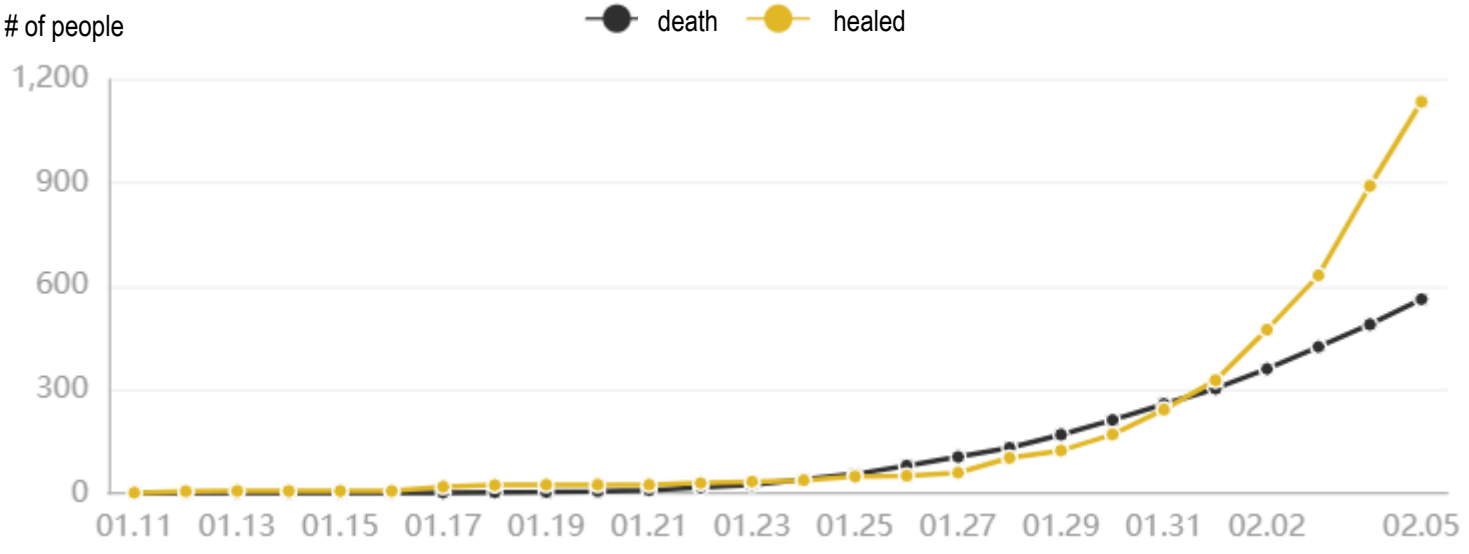
ANY QUESTION?

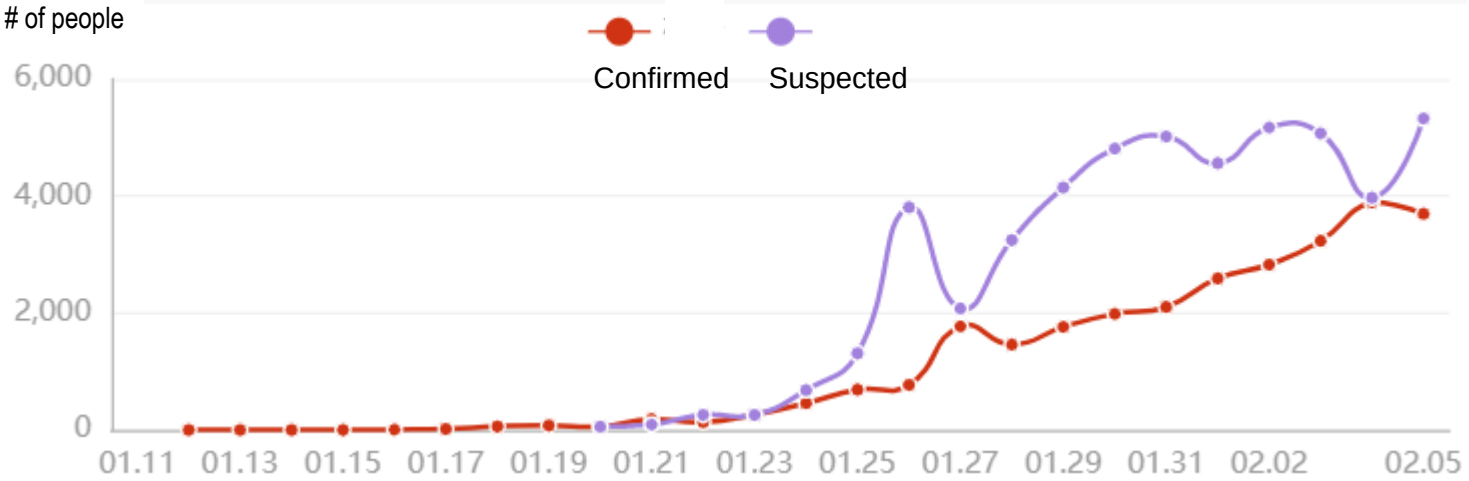
2019-nCoV pneumonia



Confirmed cases: 28083 in Mainland China, 564 death cases
19665 in Hubei province, 549 death cases

By 06:00 Feb-6, 2020





Severe impact: all businesses close for another 1 week; all travels are cancelled, reduced efficiency in construction. Delays are expected for all major projects.

90% contained wildfire: the whole society is mobilized: full isolation and good treatment

It’s manageable, and we will do it.