SRF 2023 GRAND RAPIDS

Status of SRF activities for SHINE

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SHINE

25–30 June 2023
AMWAY GRAND PLAZA HOTEL
Grand Rapids, Michigan, USA

Outline

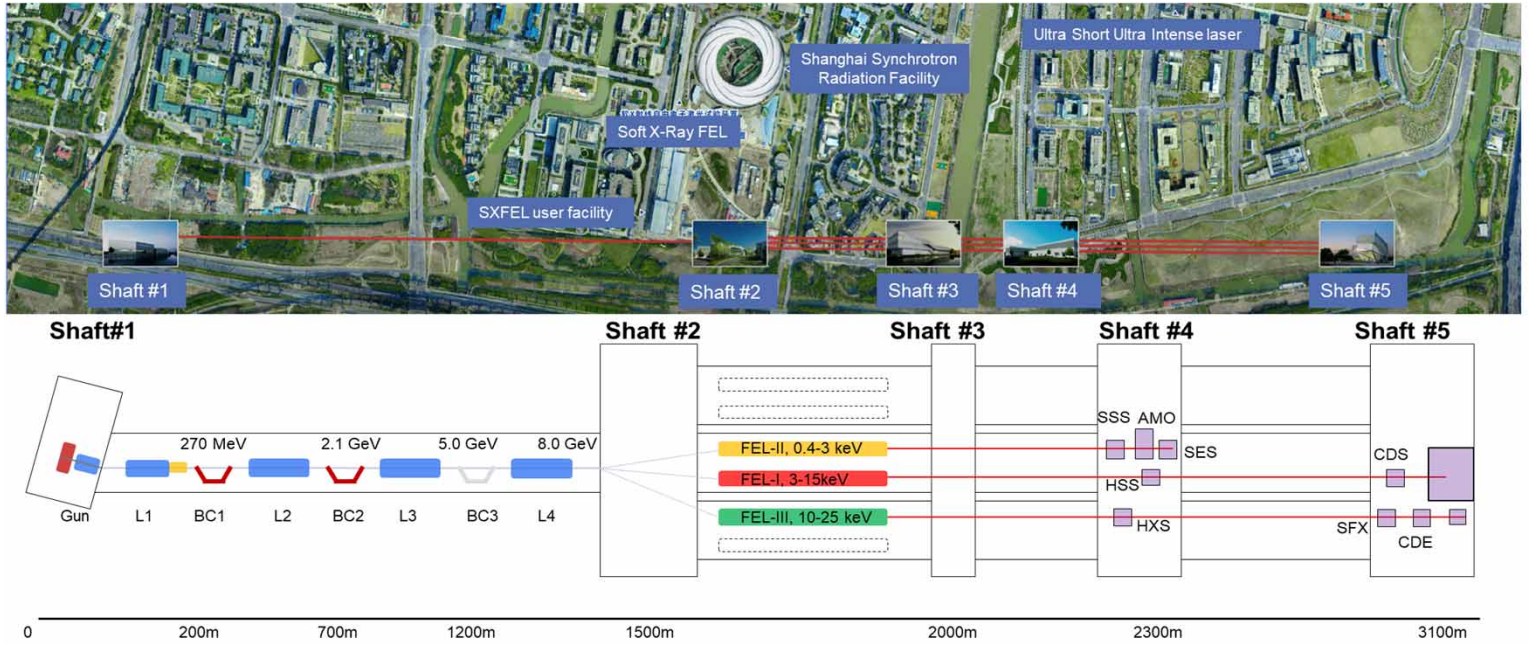
- **Introduction**
- **Progress of cryomodule**
- **Status of key components**
- **SRF Infrastructures**
- **Summary**

SHINE

An overview of SHINE

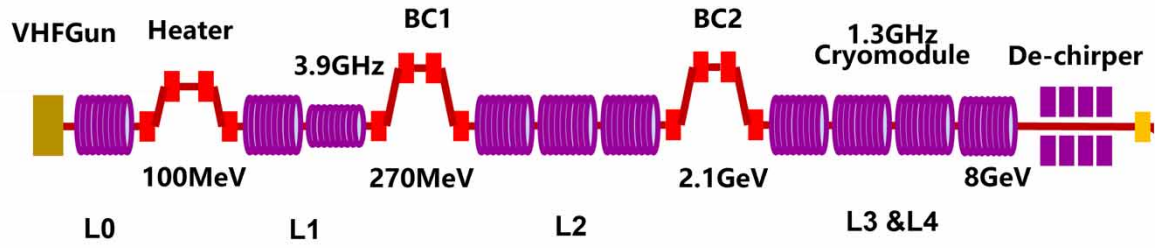
SHINE: Shanghai HIgh repetitioN rate XFEL and Extreme light facility

- Launched in April 2017, groundbreaking in April 2018, aiming at the first lasing in 2025.



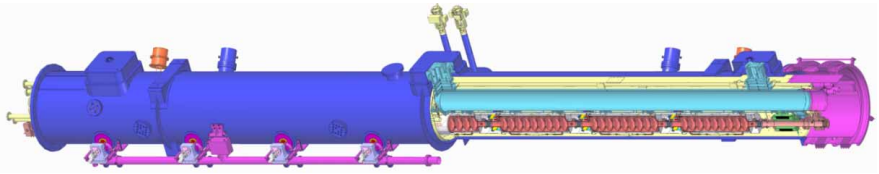
- An 8 GeV SRF linac, 3 undulator lines, generating photons from 0.4-25 keV
- 3 X-ray beamlines, delivering up to 1MHz photon pulse
- 10 experimental stations
- A 100 PW laser facility
- Total length: 3110 m; -29.0 m underground

SHINE Linac requirements



Linac	No. of CM's	Avail. Cavities	Powered. Cavities*	Gradient (MV/m)	Eout (MeV)
L0	1	8	7	16.3	100
L1	2	16	15	14.8	326
HL	2	16	15	13.1	265
L2	18	144	135	15.5	2229
L3	24	192	180	15.5	5120
L4	30	240	226	15.5	8734

- **SHINE Linac requirements on cryomodules (CMs)**
  - 75 CMs with 1.3 GHz high-Q cavities
  - 2 CMs with 3.9 GHz cavities
- **Basic requirements of 1.3GHz high-Q cavities**
  - At 2K: $Q_0 \geq 2.7E+10$ @ Eacc= 16 MV/m, max Eacc>19 MV/m (same as LCLS-II)



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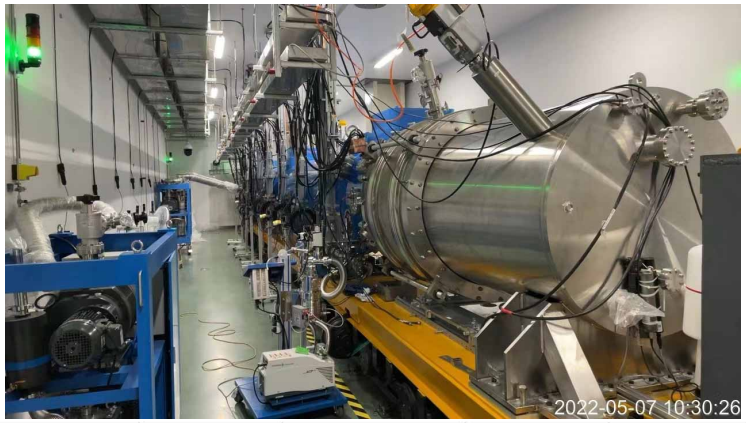
Prototype CM1 with BCP'ed cavities

- **CM1(2nd round): standard 8-cavities** (BCP refurbished), successfully cooled down, and has been RF tested in June 2022.
- **Reached its basic goal** (V_{tot}>128 MV, average Q_0>1.0E+10, I_{dark}<1 nA).
- Improvements on clean assembly are needed.



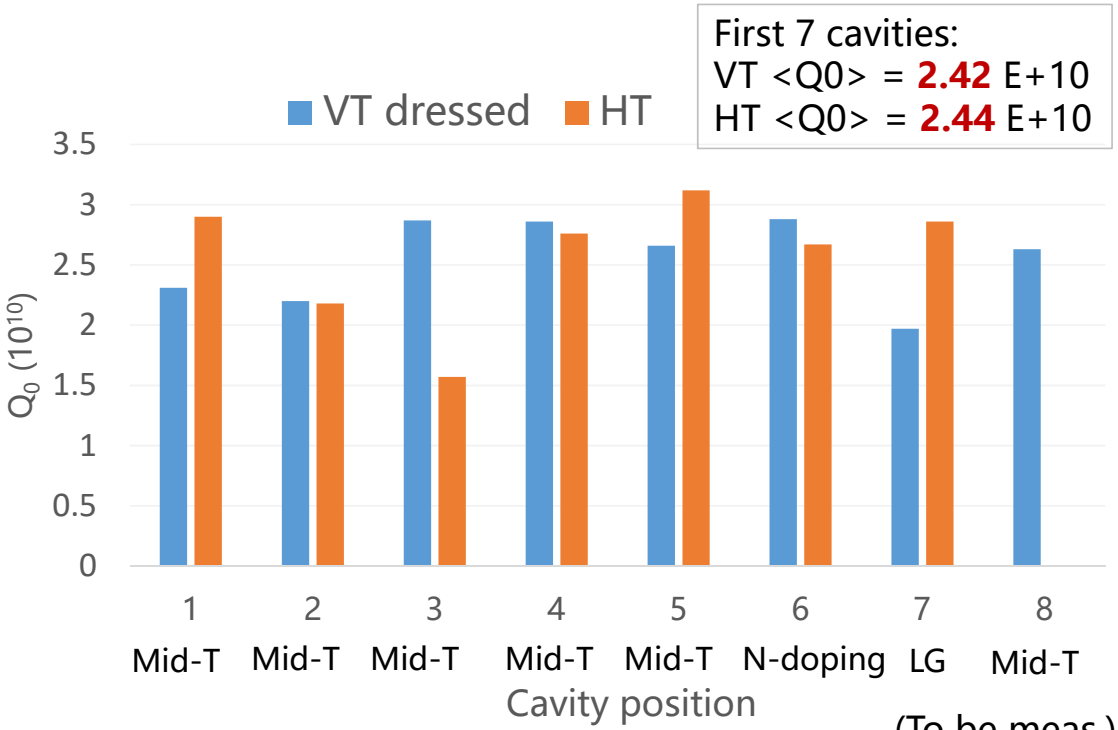
Horizontal Test results of 1st CM with 8 BCP'ed cavities (Q_0 test at ~130.4 MV)

Position	Cavity	Coupler	Eacc (MV/m)	CW Volt (MV)	CW Volt (MV)	Pdiss (W)	Pdiss (W)	Q0	Ave. Q0	Dark Current (nA)	Total Dark Current (nA)
#1	HJ002	HJ006	15.24	59.2		75.5	194.0	1.12E+10		0.40	
#3	GJ002	DJ002	18.67								
#5	BJ003	CJ001	17.88								
#7	BJ002	HJ003	5.23 (FE limit)		130.4				1.06E+10		0.96
#2	BJ001	HJ002	17.66	71.2		118.5		1.03E+10		0.56	
#4	BJ004	HJ001	15.41								
#6	GJ001	GJ001	19.55								
#8	GJ004	GJ002	15.99								

SHI

Prototype CM2 with high-Q cavities

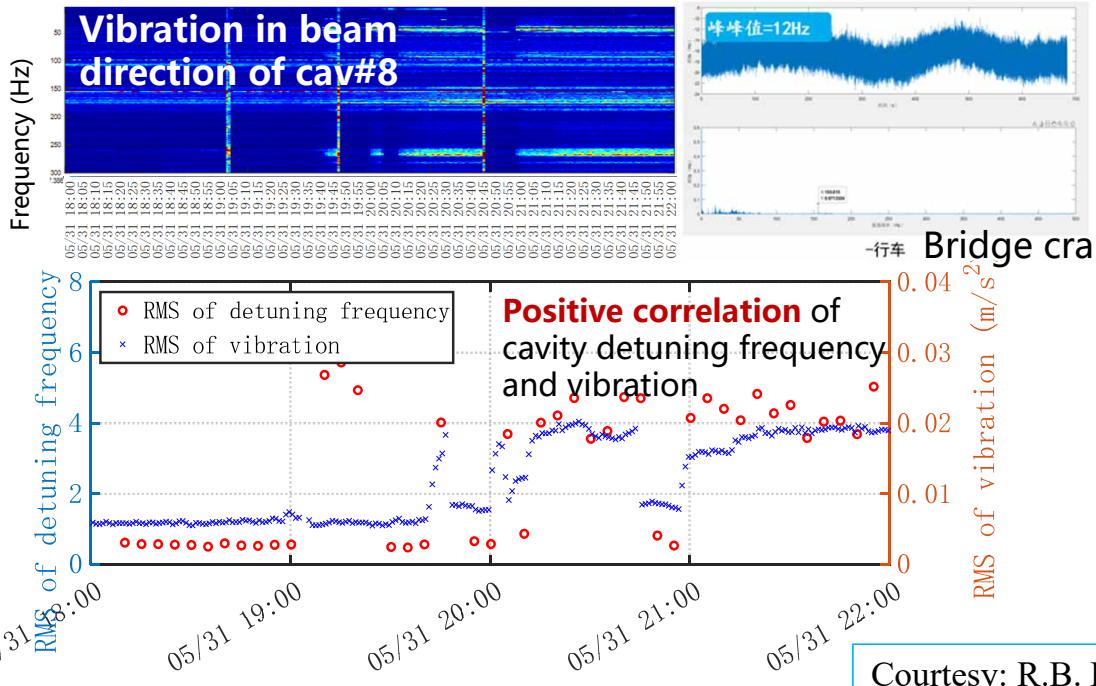
- **CM2：** standard 8-cavities, including **6 midT-baked, 1 N-doped prototype cavities and 1 LG cavity, preliminary tested in Jan 2023,** and re-start test recently.
- **HT results in Jan 2023:**
  - Max Voltage in CW > 136 MV;
  - Q_0 measured after 12h stable operation at total voltage of 128 MV.
  - High Q_0 are preserved in HT;
  - Low Q on Cav#3: under investigating, abnormal temperature on FPC 5K/45K intercepts observed.

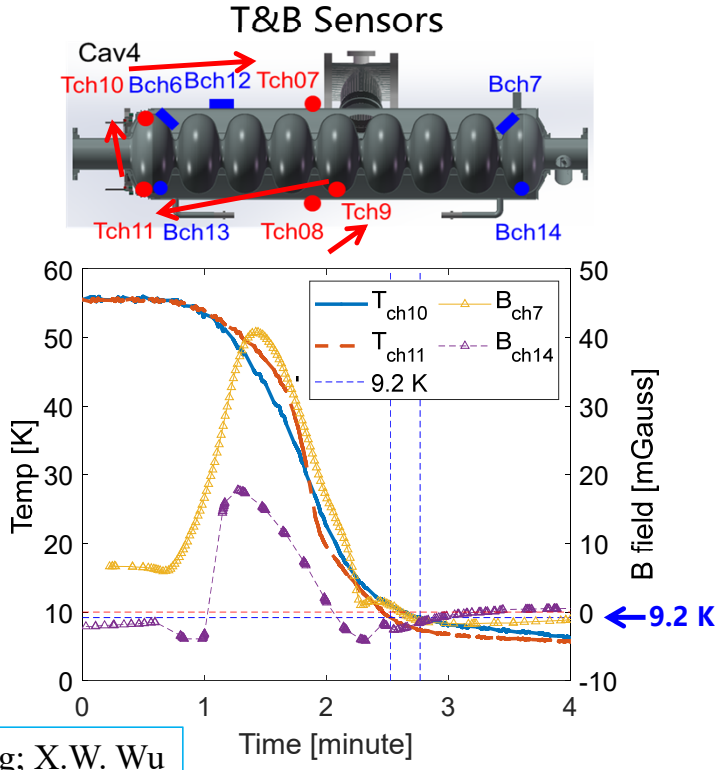


(To be meas.)

More studies with prototype CMs

- **Microphonics suppressing** studies are on going. Accelerometers mounted on cavity tuners (beam direction) to monitor vibration, detuning freq. <10 Hz achieved on prototype CM1 in ATH1.
- **CM fast cooling** studies have been carried out to achieve higher thermal gradient for flux expulsion. More studies will be continued.

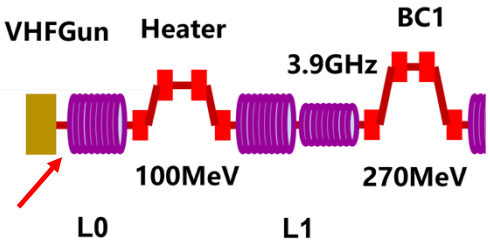


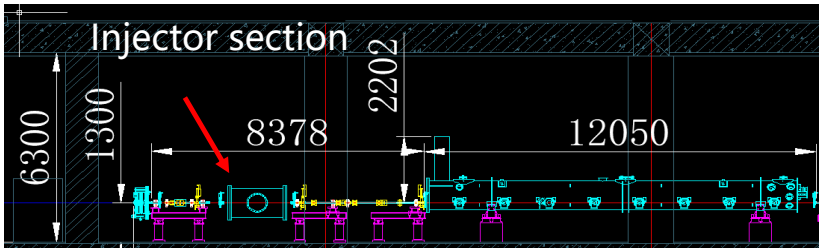


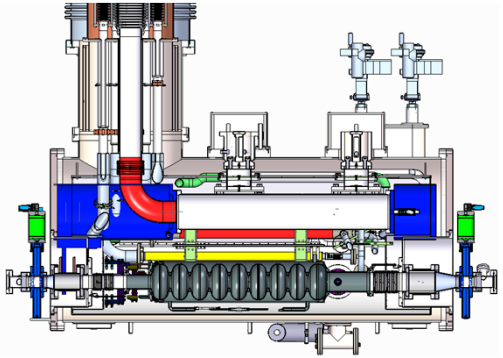
Courtesy: R.B. Deng; X.W. Wu

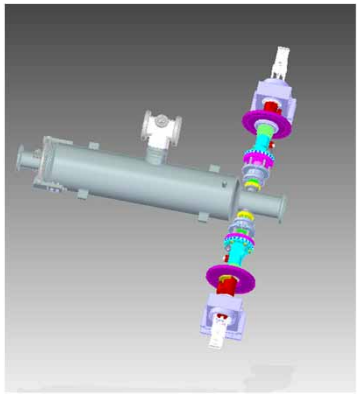
CMs under preparation for injector section

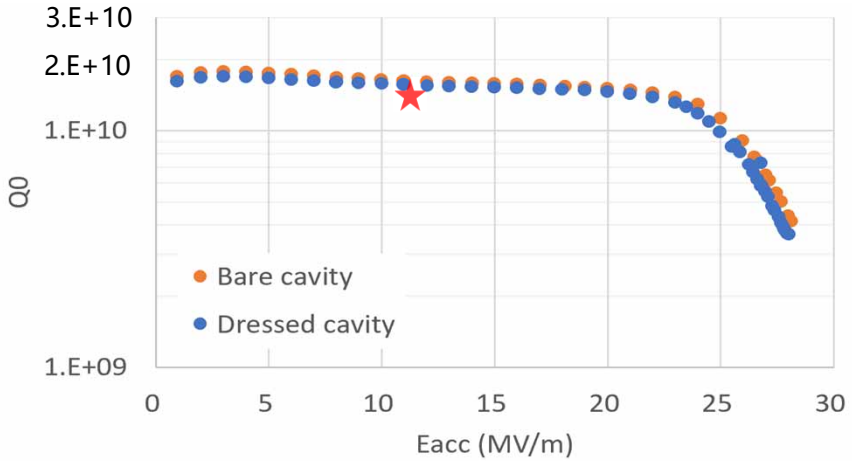
- The special CM of injector with one twin-FPC cavity is under assembly, and the 8-cavities CM of L0 is in preparation as well, aiming to install in the tunnel in the beginning of 2024.











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Vertical test results of the BCP’ ed double-fed cavity (Manufactured by HERT, treated by SHINE)

String clean assembled: Cavity + HOM absorbers

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High-Q cavity prototypes - strategy

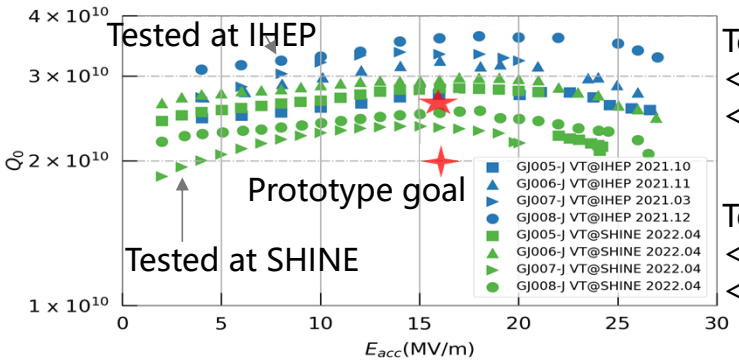
- In order to reduce risk, and to explore the engineering application of LG cavities
- Three domestic groups, 8 prototype cavities each (4 high-Q), developed independently since the end of 2018.
- In parallel, collaboration with DESY, 4 LG cavities developed

	Domestic (company + institution)			International
Groups	**G1 (HERT+IHEP)**	**G2 (OSTEC+PKU)**	**G3 (HIT+SARI)**	**Collab. with DESY**
N. cavities	4 high-Q	4 high-Q	4 high-Q	4 LG
Nb materials	TD FG	NX LG & FG	TD&NX FG	NX LG
1.3GHz cavity manufacturing	HERT	OSTEC	HIT	RI
Cavity-processing	NX site + IHEP	NX site + PKU	SHINE at Wuxi site	RI
High-Q recipes	EP + Mid-T	BCP/EP + Mid-T	EP+N-doping/mid-T	(EP+120C baking)
VT	IHEP/SHINE	PKU	SHINE	DESY/SHINE

High-Q cavity prototypes – results

- Almost all cavities **meets the prototype goal: Q_0≥2.0E+10 @16MV/m, max Eacc > 19 MV/m**
- **Domestic companies: two are chosen** for cavity manufacturing; And cavity processing in Wuxi.

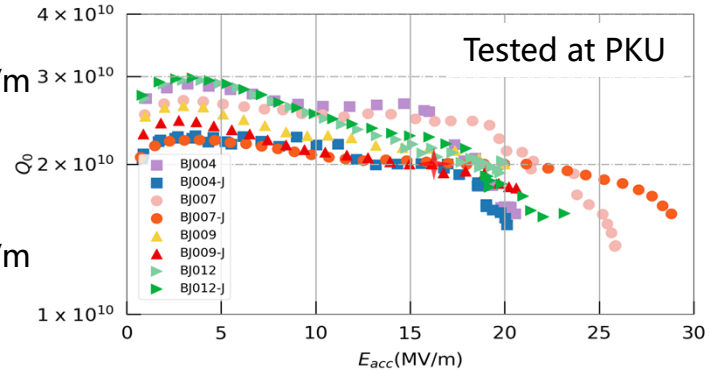
G1 (HERT+IHEP): 4 FG, Mid-T baking



Tested at IHEP
<Eacc> = 25.1 MV/m
<Q0> = 3.2 E+10

Tested at SHINE
<Eacc> = 23.9 MV/m
<Q0> = 2.7E+10

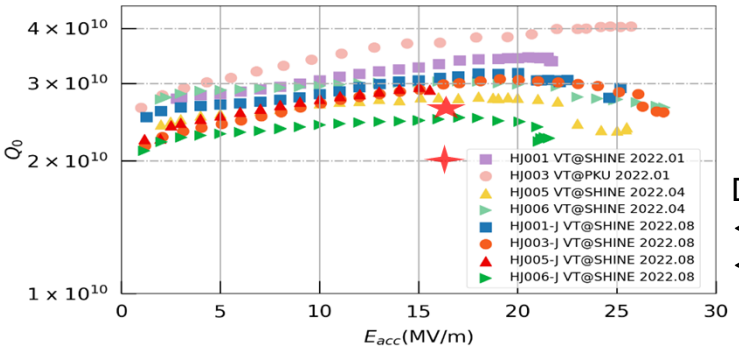
G2 (OSTEC+PKU): 2 LG+2FG, BCP/EP + Mid-T



Bare cavities
<Eacc> = 23.9 MV/m
<Q0> = 2.3E+10

Dressed cavities
<Eacc> = 24.2 MV/m
<Q0> = 2.1E+10

G3 (HIT+SARI): 2 N-doping + 2 mid-T

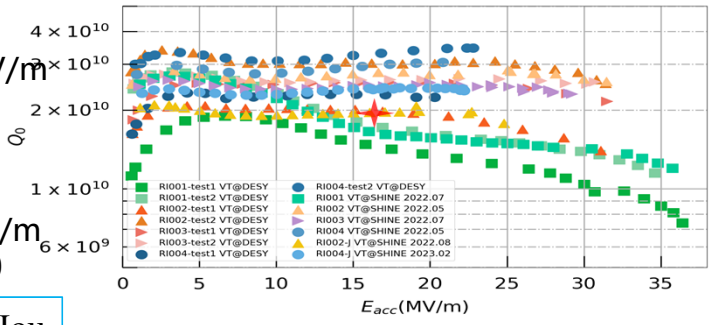


Bare cavities
<Eacc> = 24.9 MV/m
<Q0> = 3.0 E+10

Dressed cavities
<Eacc> = 22.7 MV/m
<Q0> = 2.85 E+10

Courtesy: H.T. Hou

4 LG (Collab. With DESY): EP+120C



Bare cavities
VT2@DESY
<Eacc> = 29.9 MV/m
<Q0> = 2.7 E+10

Bare cavities
VT@SHINE
<Eacc> = 29.3 MV/m
<Q0> = 2.5 E+10

SC cavities ordered for SHINE project

- In total, **4 cavity manufacturers chosen**: two qualified domestic companies, and two mature international companies

- **Cavities contracted:** 264 cavities, in two batches, around half domestic and half international
  - Small-batch: 8 cavities each, most fabricated
  - Medium-batch: 40~72 cavities each, in preparation of Nb materials

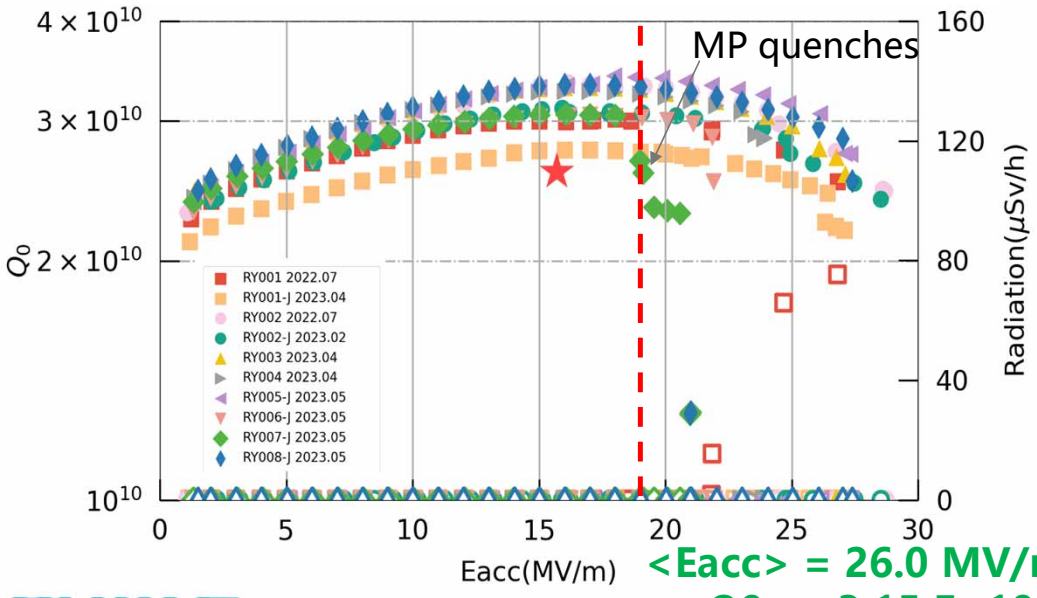
	Domestic		International	
Nb materials	TD	NX	NX	NX
1.3GHz cavity manufacturing	**HERT** (8+72)	**OSTEC** (8+40)	**RI** (8+60)	**ZANON** (8+60)
High-Q recipes	Mid-T baking, N-doping		N-doping	
Cavity-processing	**SHINE facilities at Wuxi Creative**		**RI**	**ZANON**
VT	SHINE (some at DESY)			

Status of small-batch high-Q cavities

- International cavities (RI and ZANON): N-doping, 3/60 recipe applied
- Domestic cavities (~half half): N-doping and mid-T baking
- So far, **two production lines have been qualified** by small batch cavities: One international and one domestic.
- Cavities of the other two lines are underway (surface treatment and waiting for VT)

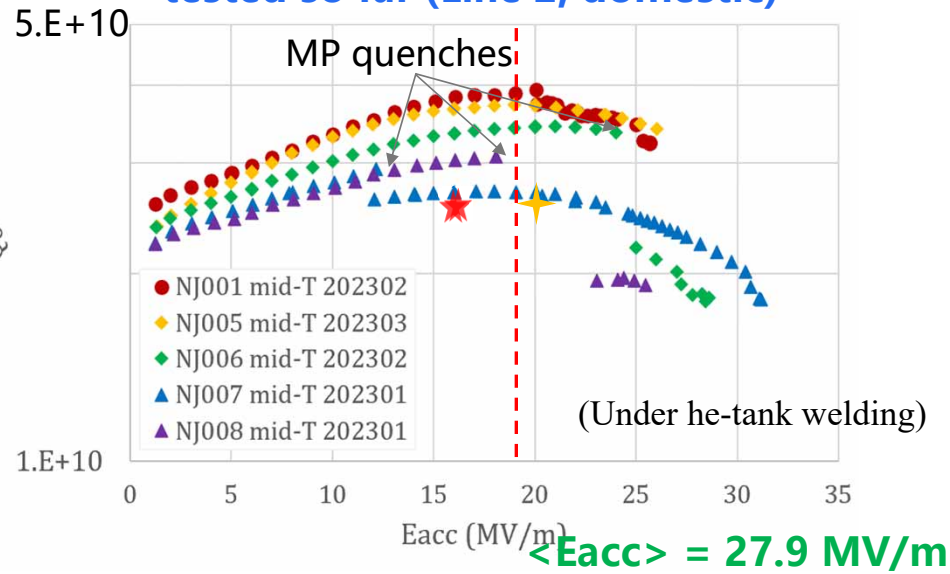
SUSPB039, Yue Zong et al.

All the 8 N-doped dressed cavities (Line 1)



<Eacc> = 26.0 MV/m
<Q0>= 3.15 E+10

All the mid-T baked bare cavities tested so far (Line 2, domestic)



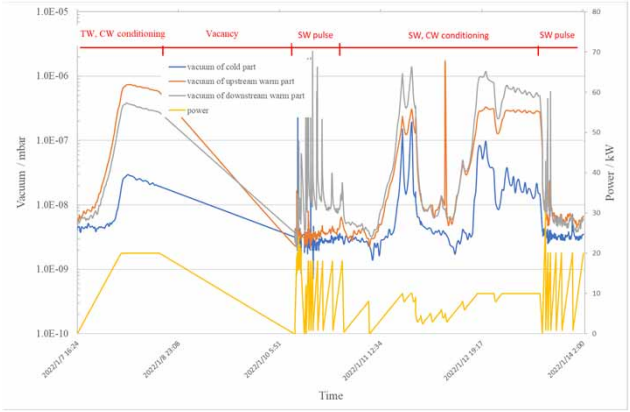
<Eacc> = 27.9 MV/m
<Q0> = 3.3 E+10

Fundamental Power Coupler and HOM absorber

- **30 1.3 GHz FPC** prototypes have been manufactured and power conditioned with 14-kW traveling wave (TW) and 7-kW standing wave (SW) in CW mode.
- The first two **3.9 GHz FPCs** have been fabricated, surface treated, vacuum baked and power conditioned with 2.2-kW TW and 2-kW SW in CW mode.
- The first two **beam line HOM absorber** prototypes with silicon carbide material have been designed, fabricated, and preliminary tested.

Poster WEPWB102, Zhenyu Ma

1.3GHz FPC prototype



1.3GHz FPCs RF conditioning historical curves

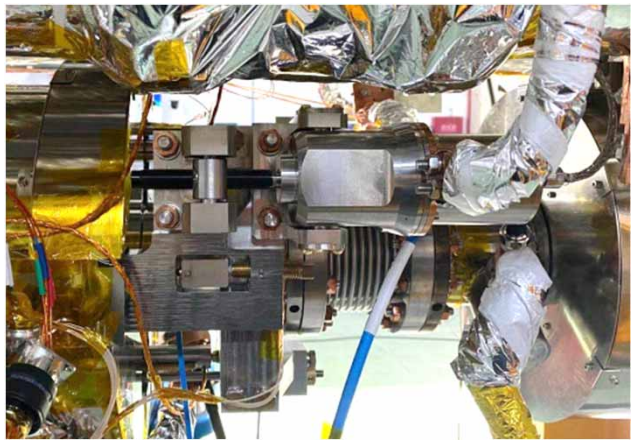
3.9GHz FPC prototype sub-assemblies

SHINE

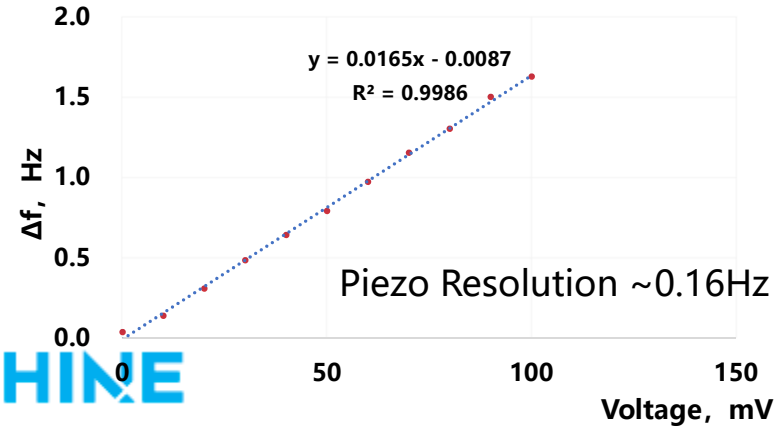
S.W. Xiang

1.3 GHz Cavity Tuner

■ **24 tuner prototypes** have been fabricated, tested and verified: **all meets specification**



Tuner mounted on cavity



Piezo Resolution ~0.16Hz

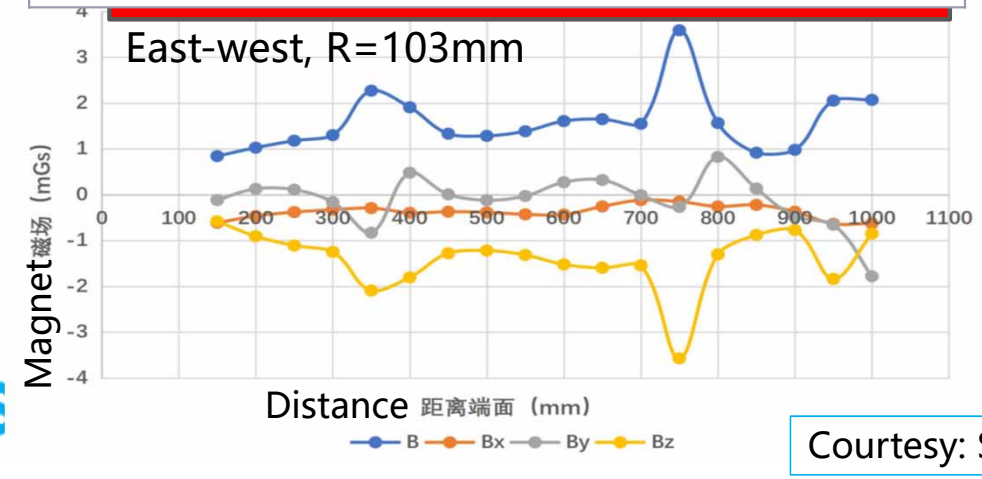
	Design Value	Measured Value
Slow tuner frequency range (Nominal)	≥250 kHz	**316kHz~350kHz**
Slow tuner frequency range (Maximum)	≥450 kHz	**525kHz~560kHz**
Slow tuner dimensional range (Nominal)	≥0.75mm	**1.2mm**
Slow tuner dimensional range (Maximum)	≥1.3mm	**1.7mm**
Slow Tuner sensitivity	1-2 Hz/step	**1.2~1.55Hz/Step**
Fast Tuner frequency range	≥1kHz	**2.7kHz**
Fast Tuner tuning resolution	~1 Hz	**<1Hz**
Tuner stiffness	~30N/μm	**34.6N/μm**
Operating conditions	Insulating vacuum 1.3E-4Pa ,T=20-60K, Radiation doses $5*10^8$rad	
Lifetime	20years	

Cavity magnetic shielding & Cold-BPM System

- **Dual layer magnetic shielding** of cavity, has been designed, fabricated and verified;
- At cavity cell region: **<5 mG**

Courtesy: Y.Z. He

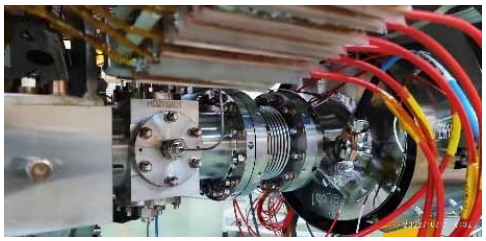
Permalloy grade	77K（1-1.3mm）		
	μi（10K）	μm（10K）	Js（T）
China-1JL0	4.5-7.5	25-35	0.85-0.90



Courtesy: S.S. Cao

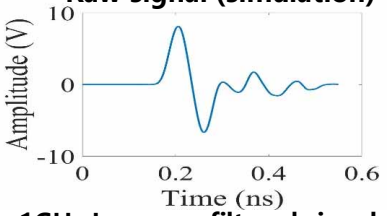
- 18 **cold BPM prototypes** have been fabricated, 4 ready for use
- Cold button feedthroughs, cold shocked and leak checked: 94% pass acceptance

Prototype & Test

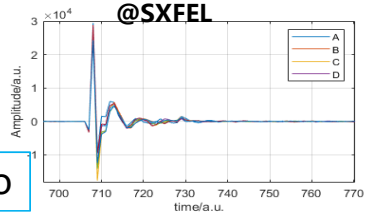


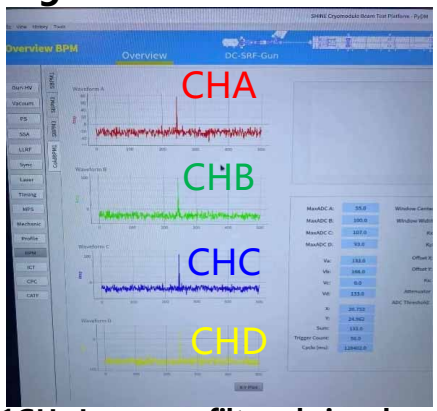
Output signal

Raw signal (simulation)



1GHz Low pass filtered signal @SXFEL



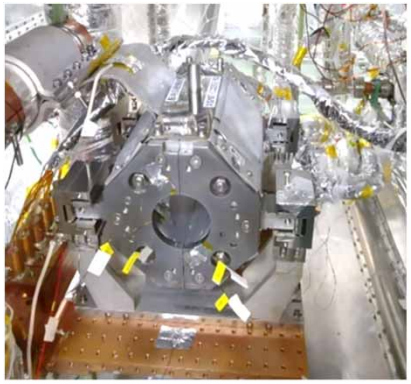


1GHz Low pass filtered signal @High Rep. TF & BCP

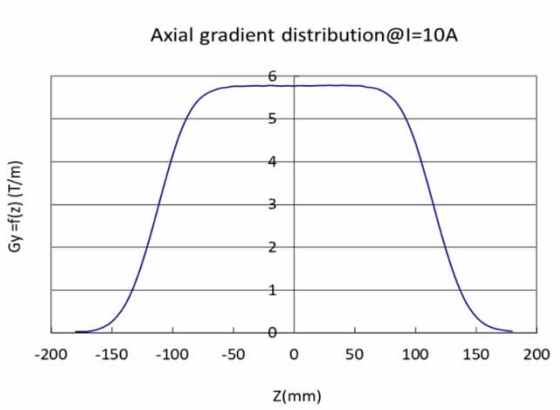
Superconducting quadrupole (SCQ) magnet

K. Zhang, J.D. Zhang

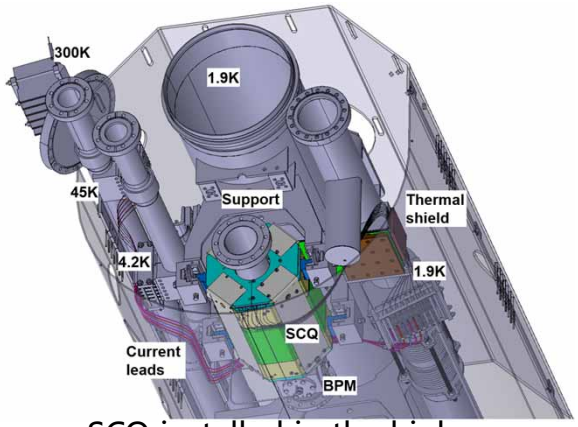
- 6 SCQ magnets fabricated, 5 of them have been tested.
- Up to now, the SCQ measurement result fulfills SHINE requirement



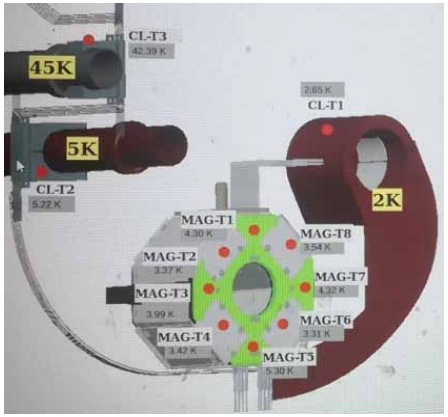
SCQ prototype



Left Fig. SCQ test at 2 K. 25 A is charged at the same time for the main quadrupole coil, the horizontal correction coil and the vertical correction coil and hold for 24 hours without quench.

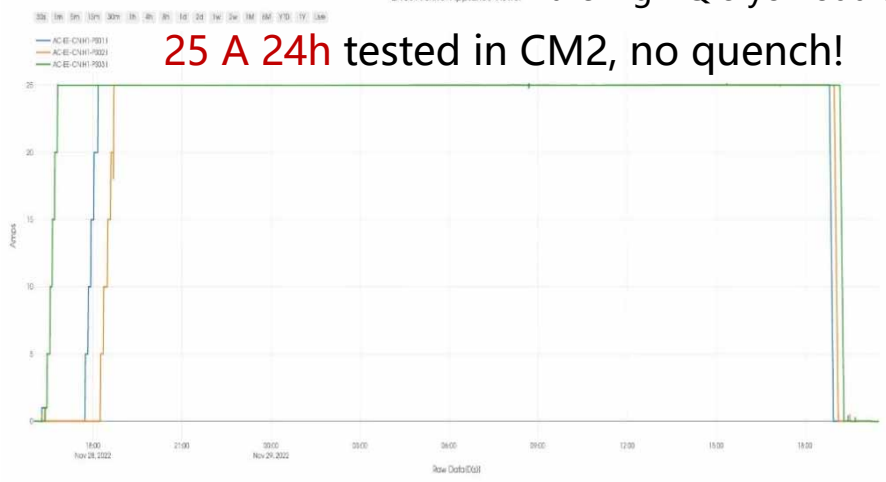


SCQ installed in the high-Q cryomodule(CM2)



Conduction cooling of SCQ in the high-Q cryomodule

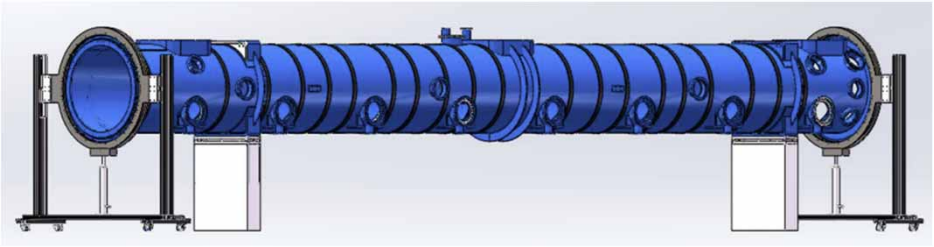
25 A 24h tested in CM2, no quench!

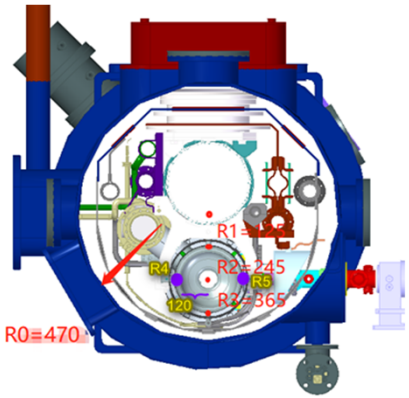


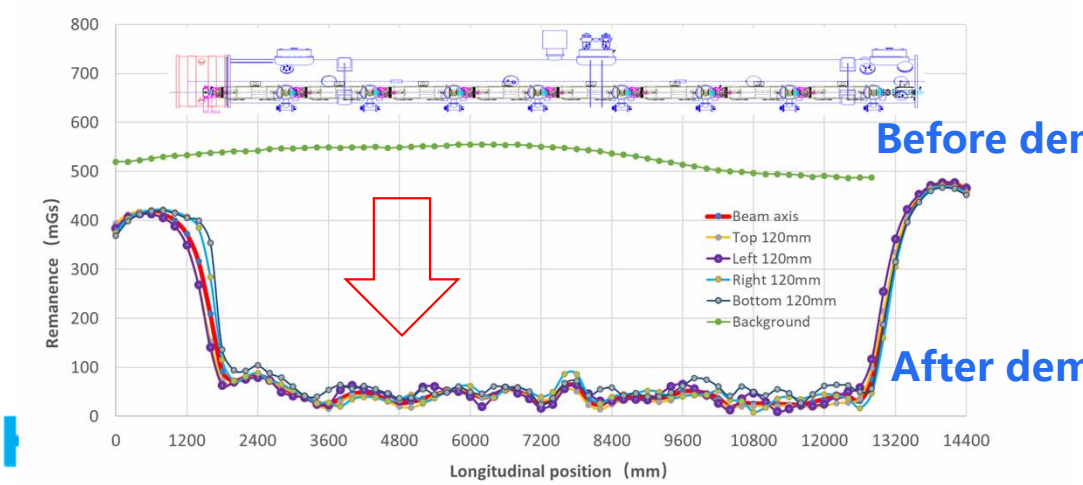
Demagnetization of Cryostat

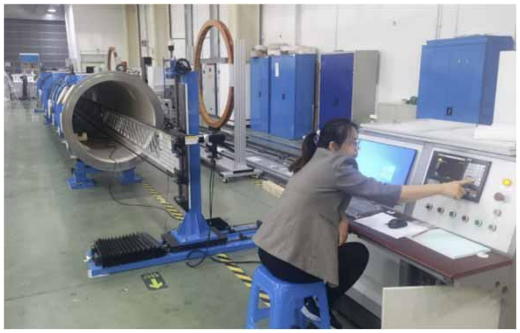
Y.Z. He, J.D. Zhang， Y.W. Huang

- **Demagnetization of Cryostat:**
  - **East-west** orientation (HT stands direction): ~50 mGs achieved at cavities region
  - **South-north** orientation (Tunnel direction): ~100 mGs after demag.
  - Studies on **whole CM demagnetization** are under study









Solid State Amplifier (SSA)

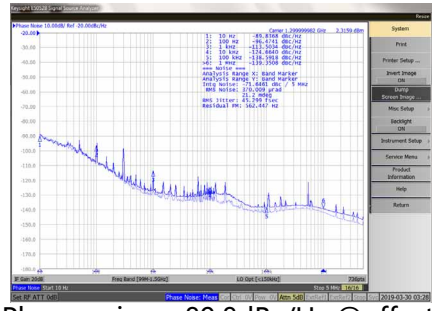
Y.B. Zhao

- 4 manufactories, developing SSA prototypes in parallel since 2019, two of them are qualified
- Small batch, 8+18 SSAs for L0 and L1 have been developed and meet the specification.
- Medium batch, 160 SSAs for L2 have been contracted and under manufacturing.

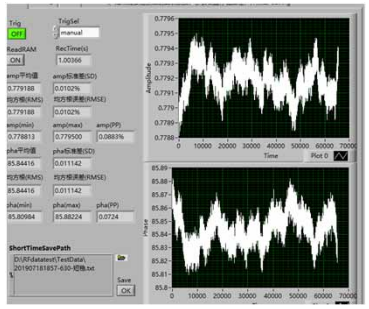
	Requirement	Test result
Frequency	1.3GHz	1.3GHz
Delay of small signal	<300ns	44ns
1 dB compression	5.2kW @0dBm	5.5kW
Bandwidth(1dB)	1MHz	2MHz@0.1dB
Phase noise	80dBc/Hz(10Hz offset@1.3)	89dBc/Hz
Amp. stability	0.1% @ 1 second	<0.1%
Phase stability	0.1° @ 1 second	<0.1°
Spur	<-70dBc	<-70dBc
Noise	<10 dB	2dB (90-88)
Harmonic	<-30 dBc	-38 dBc@5th
Efficiency	>40% (at 5.2kW)	45%

Used in beam test

Used in cavity Horizontal test



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



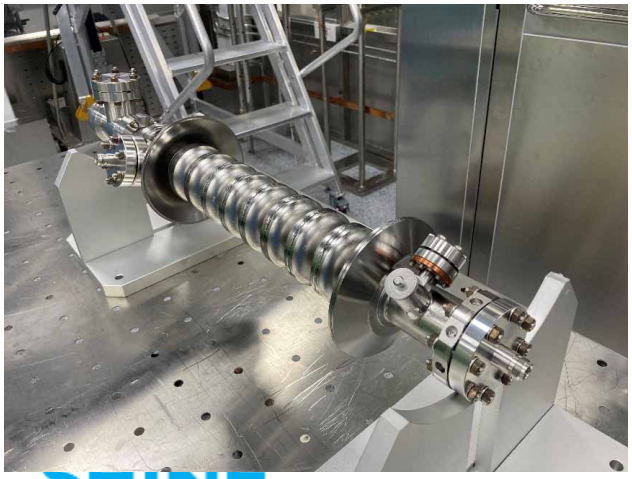
Amplitude: 0.088%, Phase: 0.072

Status of 3.9 GHz cavities

- SHINE requires two 3.9 GHz cryomodules (16 cavities) before the BC1
  - **First prototype of dressed cavity has been verified in vertical test**
  - Second prototype of bare cavity is under treatment
  - Mass production of 10 cavities is under fabrication (1st cryomodule)
- See Xiaowei Wu’ s talk on Thursday 8:00 am
  - “Development of 3.9 GHz 9- cell Cavities at SHINE”

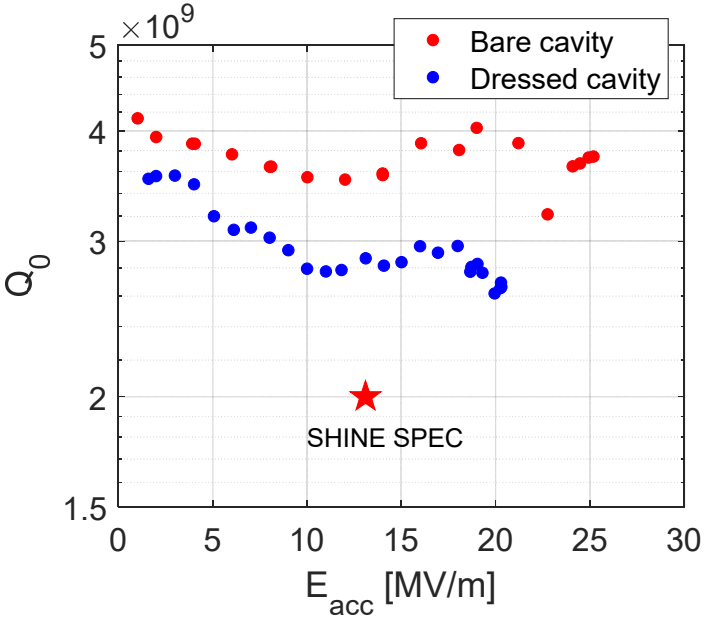
Xiaowei Wu’ s talk on Thursday

Bare cavity



Dressed cavity

Performance of first prototype



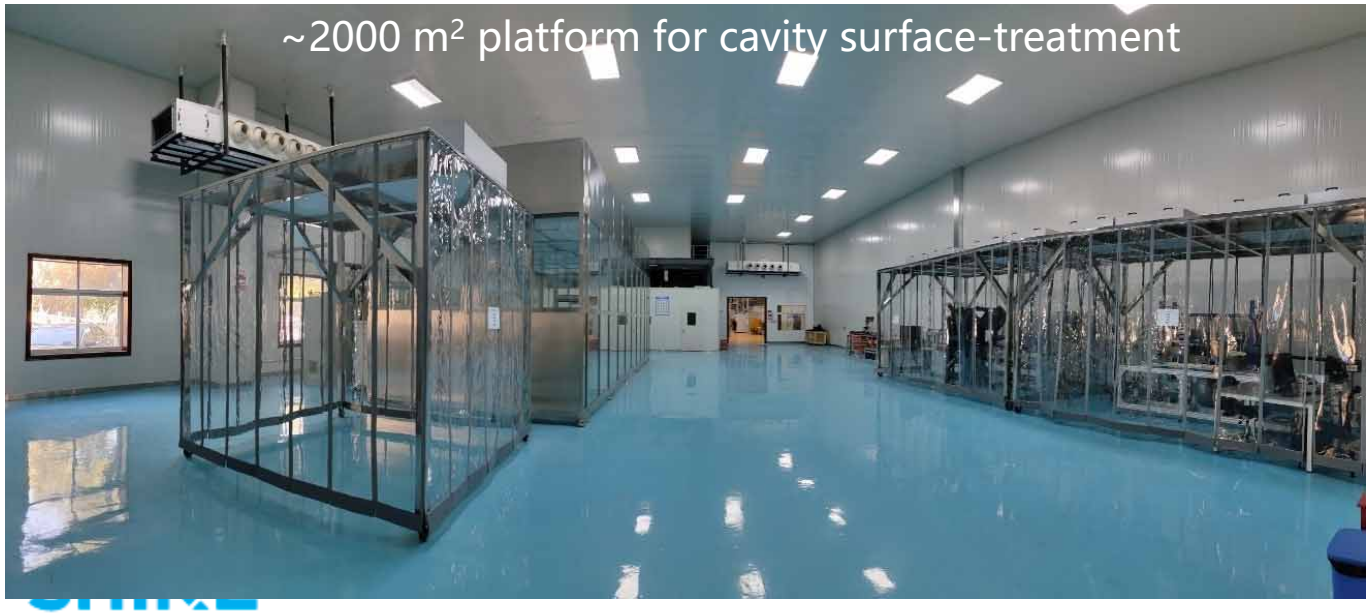
Outline

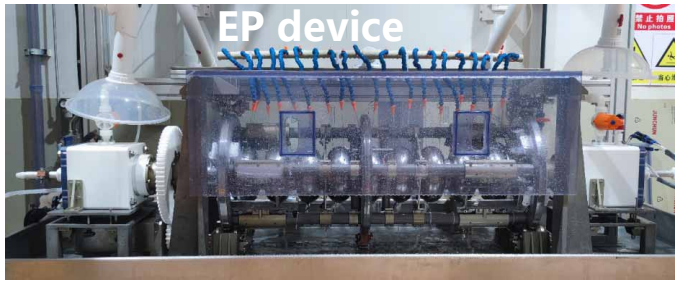
- Introduction
- Progress of cryomodule
- Status of key components
- ➢ **SRF Infrastructures**
- Summary

SHINE

Infrastructure for cavity surface treatment

- **Cavity surface-treatment platform** (co-built)**:** SHINE facilities at Wuxi Creative
- **Goal**: R&D and mass production for cavity surface-treatment
- **Design:** Dealing with all the procedures after cavity fabrication, and before vertical test
- **Status:** Commissioning and gradually put into operation since 2021, undertaking the surface-treatment of SHINE cavities from domestic companies

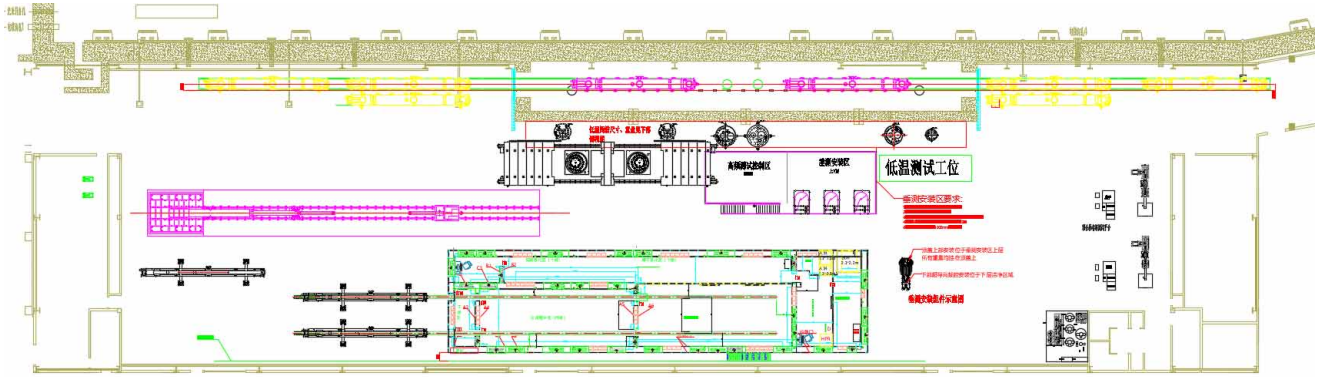


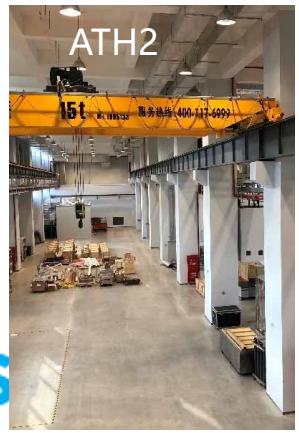


Infrastructure for CM assembly and test

S. Sun

- Two 3000 m^2 for CM Assembly and Test Halls (ATH1 & ATH2)
- Commissioning and gradually put into operation since 2021
- 3 rounds of standard CM assembled and tested

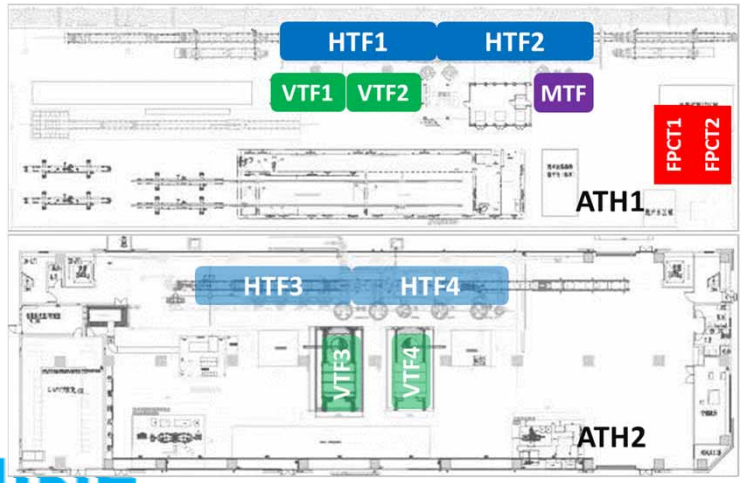


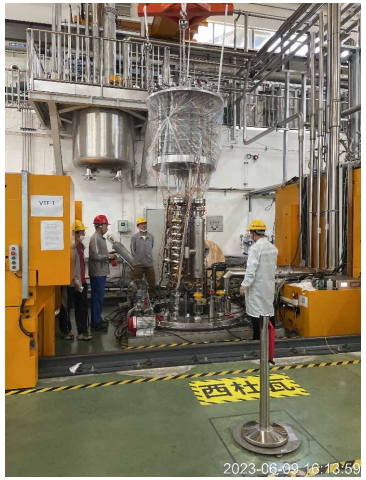


Test Stands for cavities and CMs

S.J. Zhao

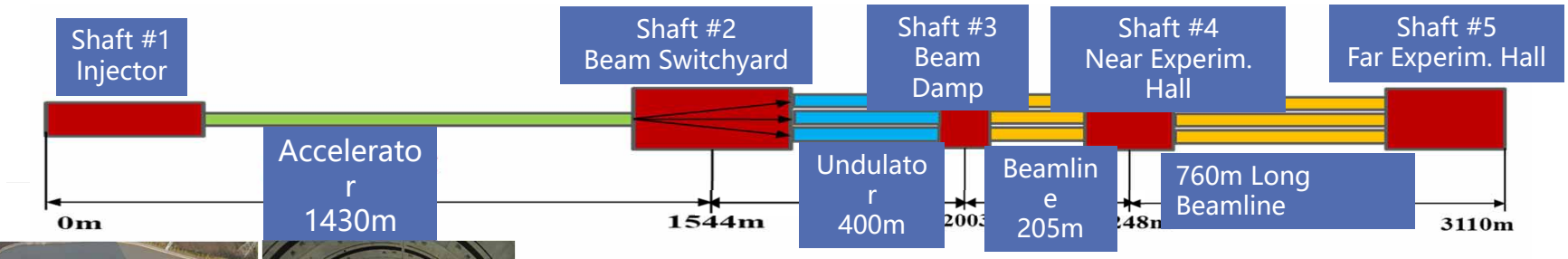
- 4 vertical test stands and 4 horizontal test stands are designed in the two halls
- In ATH1(Assembly and Test Hall), 2 vertical test stands and 2 horizontal test stands, have been constructed and **put into operation**;
- The test stands in ATH2 are expected to be completed this year;
- The Cryo distribution will be optimized to allow more effective operation of multi-stands;
- The mass flow meters will be equipped to make the Q_0 test easier than the delta liquid level method used now.





Status of the project site

- SHINE tunnel construction is completed. VHF gun arrived in the tunnel, and the 4 kW cryoplant #1 is under installation.



VHF gun arrived in the tunnel

4kW cryoplant #1 under installation

Summary

- **Two standard CM prototypes,** have been assembled and tested, reaching their basic goals. Accelerating voltage >128 MV, and high-Q are preserved in horizontal test. Further optimization and iteration are in plan.
- **SRF key components and technology** of cryomodule have been developed through prototypes, including high-Q cavity, FPC, magnetic shielding, tuner, SCQ, cBPM, SSA etc. Many **new suppliers** are qualified.
- **Both N-doping and mid-T baking** technologies have been realized with SHINE facilities and applied on small batch production, bringing good performance. Recipe for the domestic medium-batch cavities will be chosen soon.
- **SRF infrastructures** for cavity surface-treatment, CM assembly and test have been built and put into operation. Further construction to improve production capacity is expected to complete within 2023.
- Up to now, **around 1/3** of the SHINE CM components have been contracted and under fabrication.
- **CMs for injector** are under assembly, aiming to install in the beginning of 2024.
- **Many progresses, but also many challenges**

- **Many thanks to:**
  - The cooperators: DESY, INFN-LASA, KEK, PKU, IHEP, DICP etc.
  - The industrial suppliers both in international and domestic
  - The people of SHINE SRF cryomodule team, cryogenic team

Thanks for your attention!

SHINE