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

TESLA TECHNOLOGY
TTC
COLLABORATION

High Q&G activity at IHEP

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On behalf of the IHEP SRF Team

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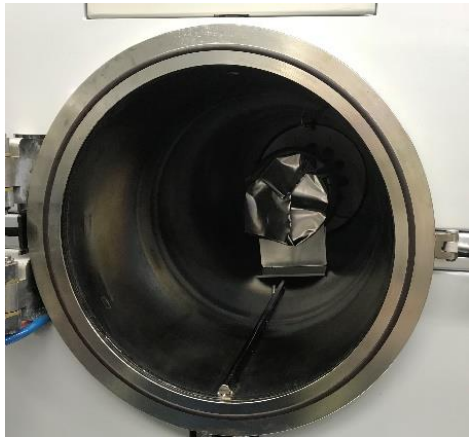
February 04, 2020

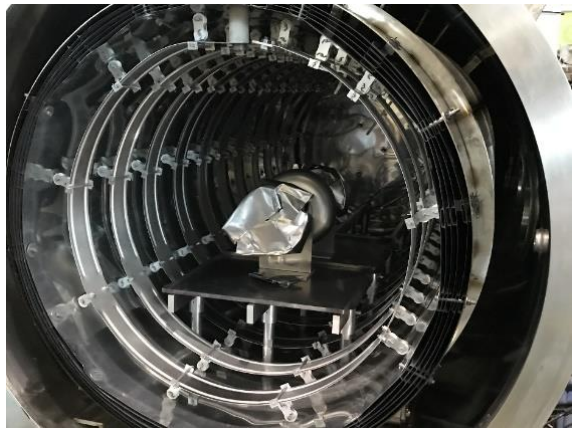
Outline

1. Facilities Development——most finished in 2019
2. High Q&G activity of 1.3 GHz Cavities
3. High Q&G activity of 650 MHz LG Cavities
4. Summary

Vacuum Furnaces for N-doping and Nb3Sn coating



Small furnace for 1-cell.
Heater placed in the outer vacuum, very high vacuum (< 2E-7 Pa)

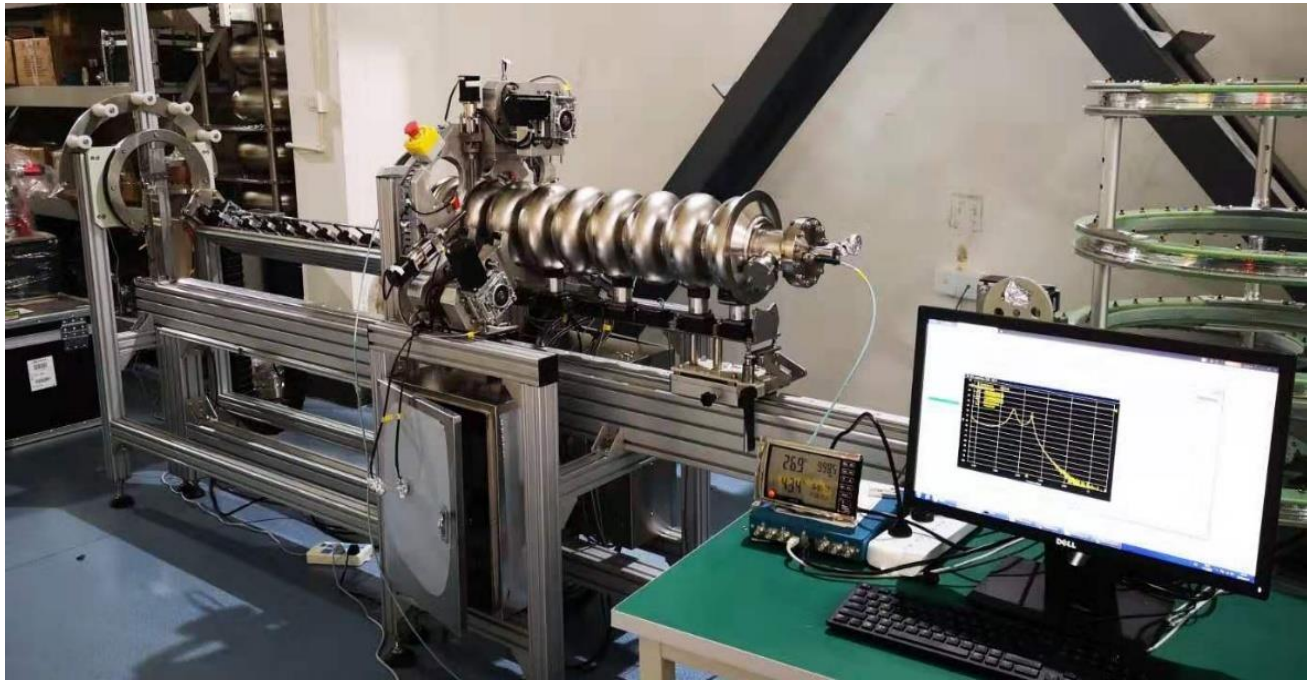


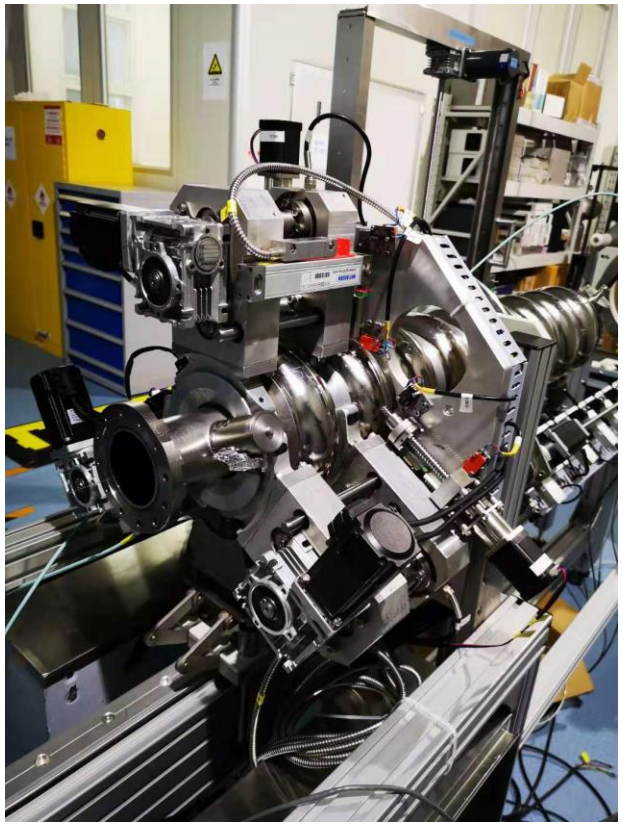
Big furnace for many shapes.
It will be transferred to PAPS soon.

The furnace for Nb3Sn coating have been completed, which reached the requirements.

IHEP New Tuning Machine

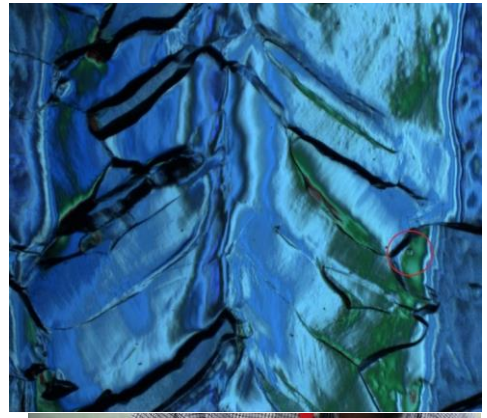
- Cavity frequency tuning and field flatness, length and eccentricity adjustment. Similar to DESY's design for XFEL.
- Need to improve automatic tuning procedure for higher efficiency (target: half day a cavity).

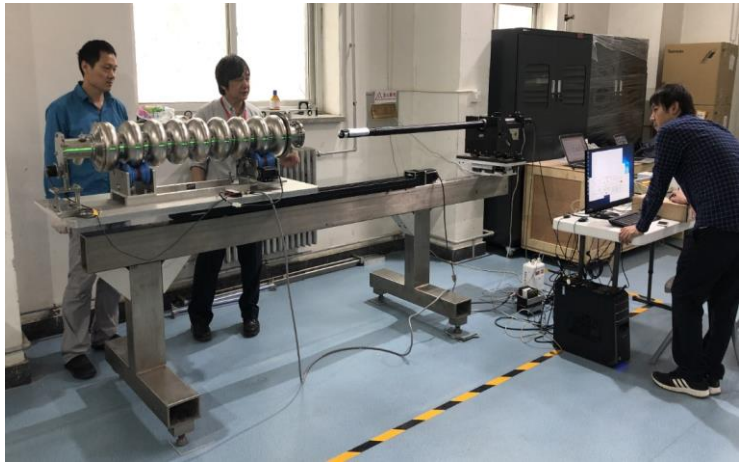


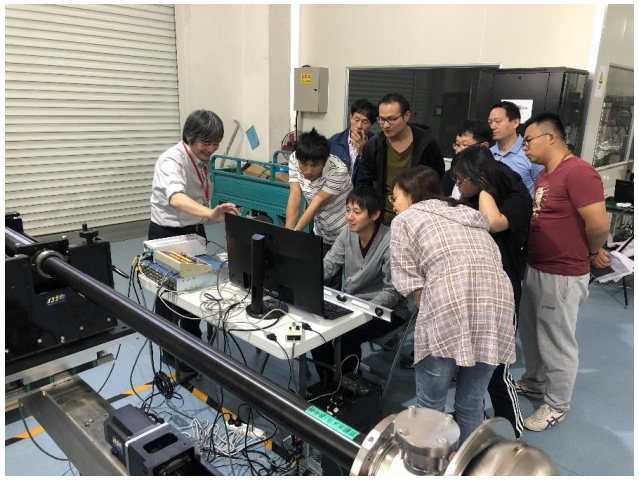


Inspection Cameras

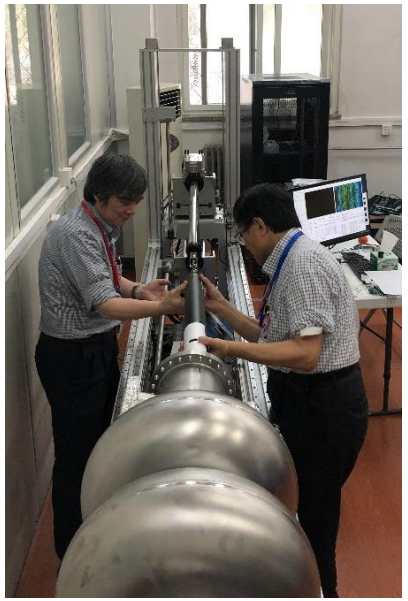
- One 1.3 GHz Kyoto camera rent from KEK. Already inspected more than eight 9-cells and tens of single cells.
- One 650 MHz / 1.3 GHz inspection camera and grinder purchased from Japan (1.3 GHz camera head and grinder head will deliver soon).

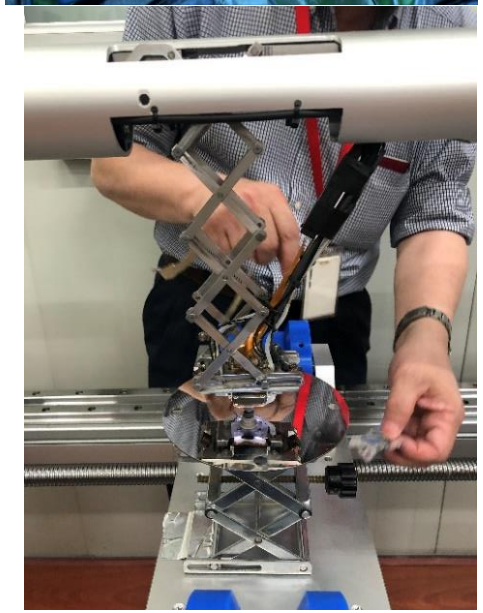






Hayano-san helped to install
KEK's 1.3 GHz camera and train IHEP people

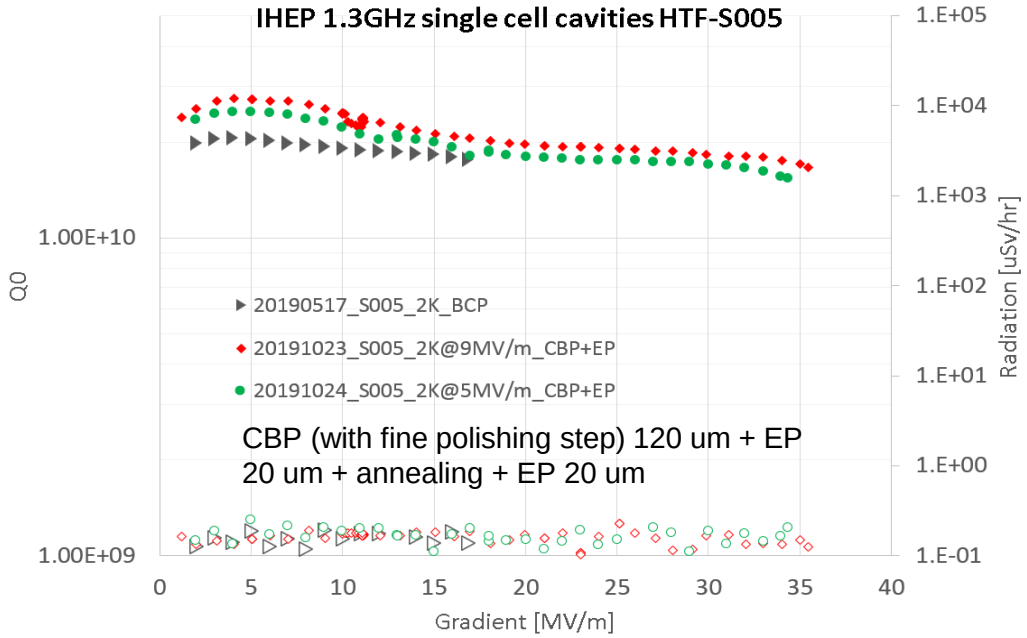




Iwashita-san and Hayano-san helped to test the 650 MHz camera and grinder

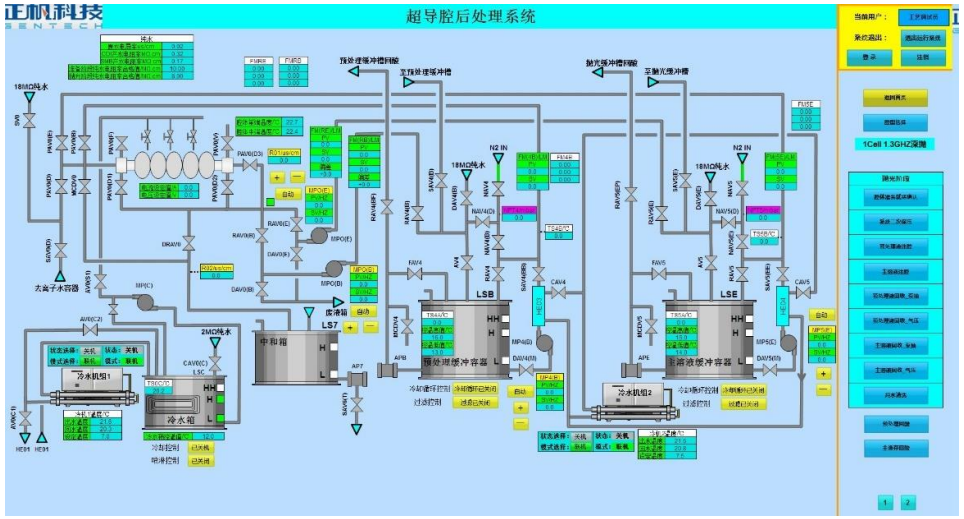
CBP (Tumbling)

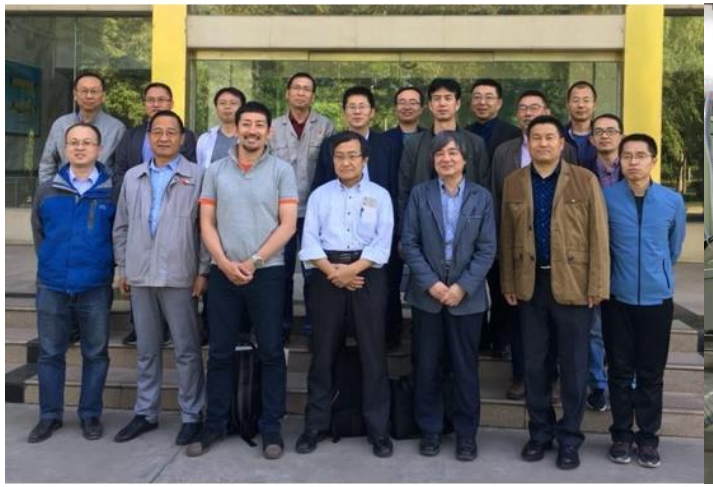
- Explore methods to replace the time-consuming bulk EP and repair bad cavities for mass production
- CBP machine for both 650 MHz and 1.3 GHz cavities
- 1.3 GHz single cell cavity repairing successful with IHEP's previous experience
- 1.3 GHz 9-cell cavity and 650 MHz cavity processing soon



IHEP EP Facility at Ningxia

- A horizontal EP facility was developed by IHEP.
- Can treat various types of cavities: 500 MHz 1-cell, 650 MHz up to 5-cell, 1.3 GHz up to 9-cell.
- Six TESLA single cell cavities reached 38 ~ 45 MV/m after EP.
- 9-cell cavity EP commissioning will start soon. Target: 40 MV/m (with 14 R&D 9-cell cavities).



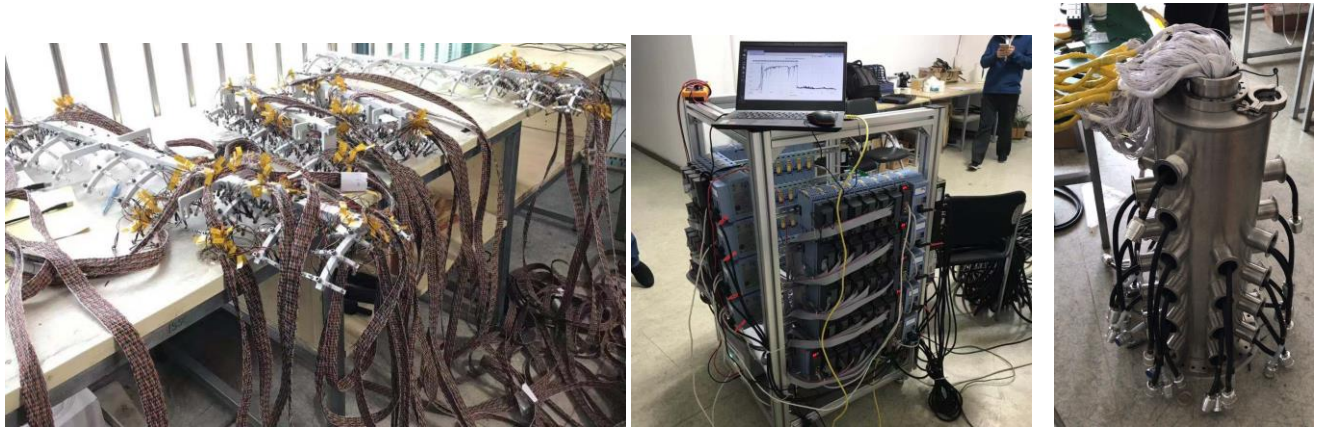


KEK experts joint EP commissioning at OTIC, Ningxia (May 2019)

Sample cavity
Roughness (Ra) after EP: ~300 nm

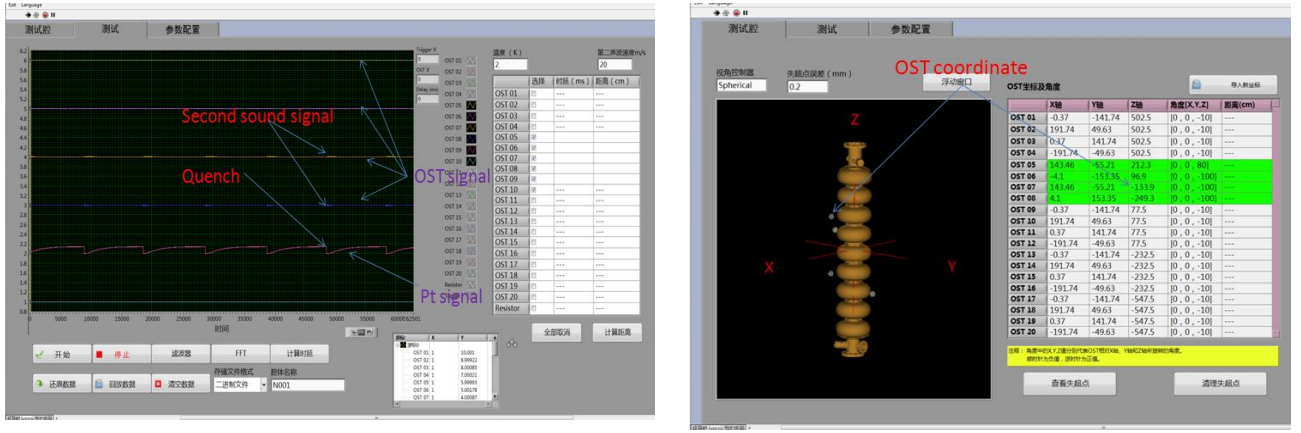
TX-Mapping and Second Sound Quench Detection System

- For 9-cell cavity: 400 carbon resistor temperature sensors, 200 PIN photo diodes X-ray sensors
- System integration completed. Will commission in PAPS SRF lab in 2020.
- Thanks for the help of Kirk Yamamoto-san from KEK.



TX-Mapping

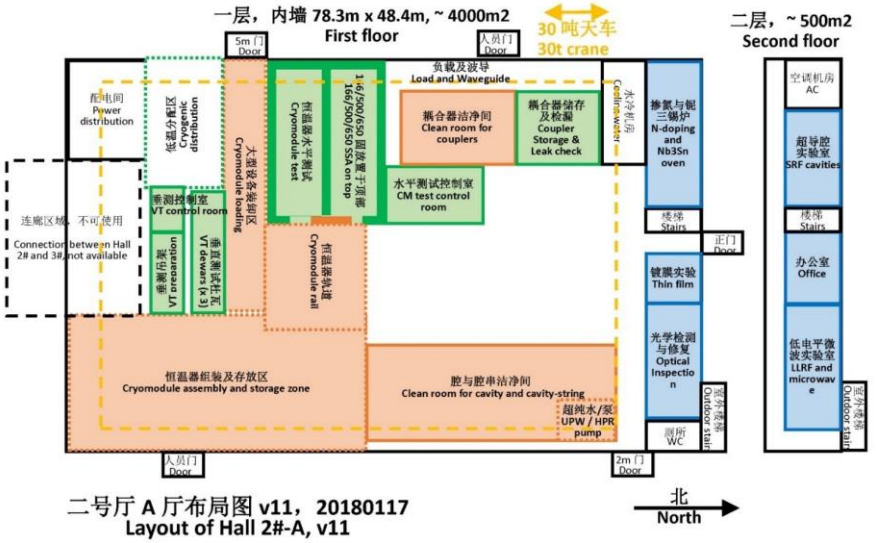
- 20 OSTs will be used for the 1.3 GHz 9-cell cavity and 8 OSTs for single cell.
- Second sound signals from OST are amplified by two 12-channel amplifier. Acquisition system: NI9222 and NI9402. LabVIEW for data saving and quench position calculation.
- Thanks for the help of Carlo and colleagues of INFN-LASA.



SSQD Position and Signal

IHEP New SRF Lab at Huairou

- 4500 m^2 SRF lab in PAPS, Huairou Science Park, north Beijing.
- Civil construction completed in summer.
- Test stands, clean rooms and other facilities installation and commissioning by mid 2020.
- 200 ~ 400 cavities (couplers) tests**,** 20 cryomodules assembly and horizontal tests per year.



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2. High Q&G activity of 1.3 GHz Cavities
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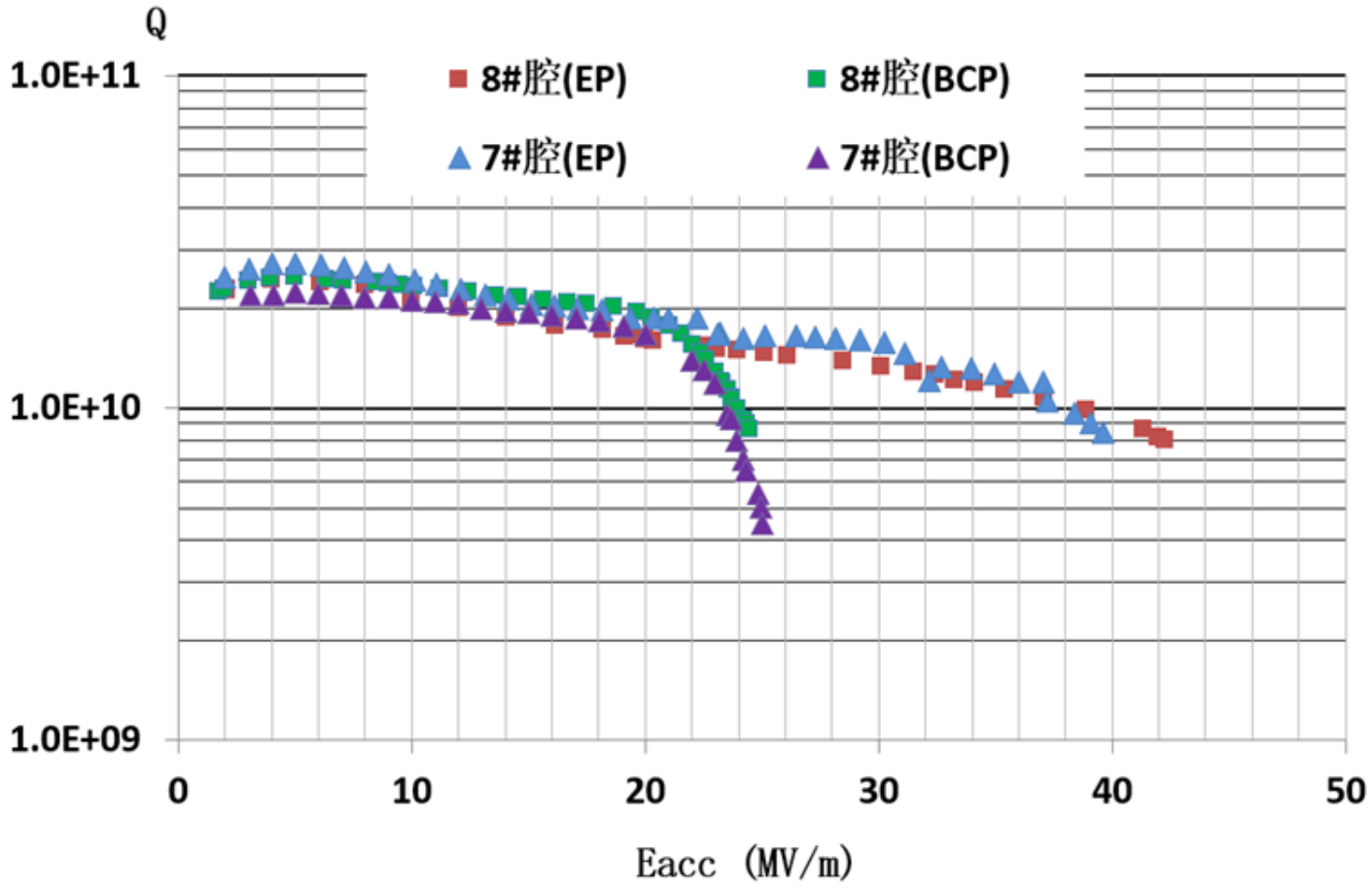
Baseline results of 1.3GHz 1-cell cavity

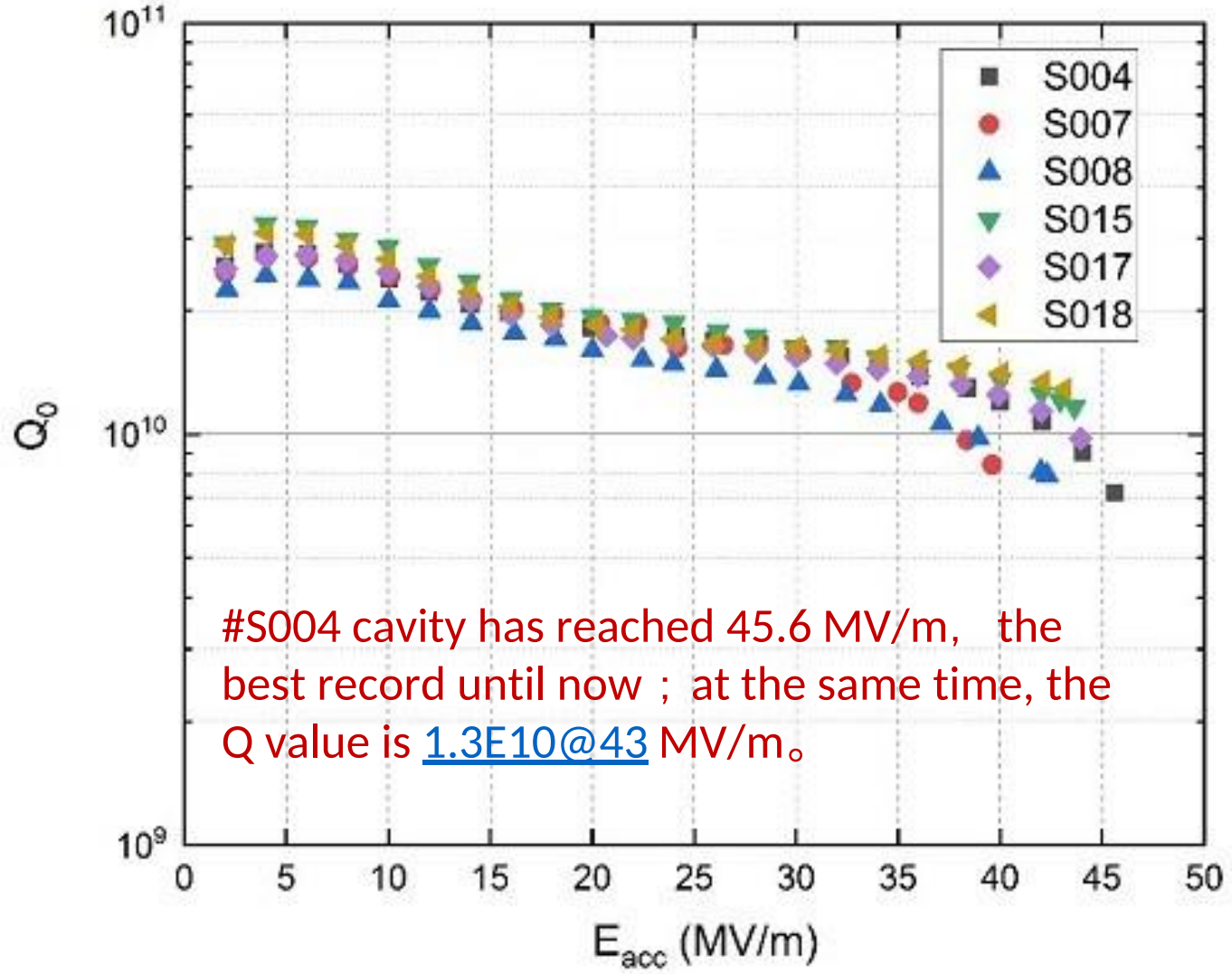
gradient improve by EP

With IHEP's newly developed EP equipment, IHEP is able to reach 40 MV/m for 1.3 GHz 1-cell cavities.

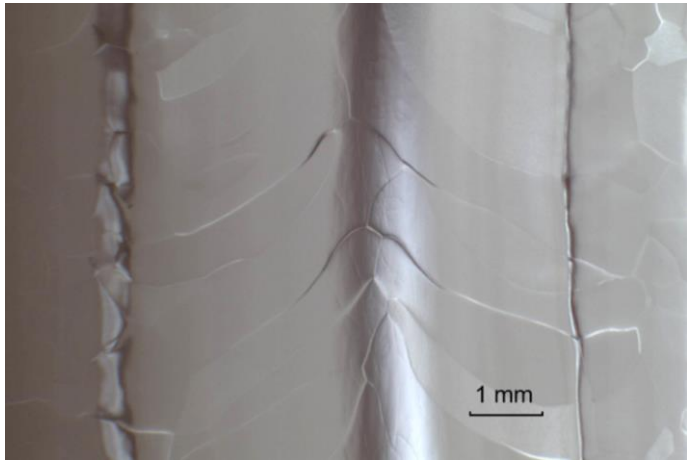


Baseline results of 1.3GHz 1-cell cavity

gradient improve by EP



#S004 cavity has reached 45.6 MV/m, the best record until now ; at the same time, the Q value is 1.3E10@43 MV/m。



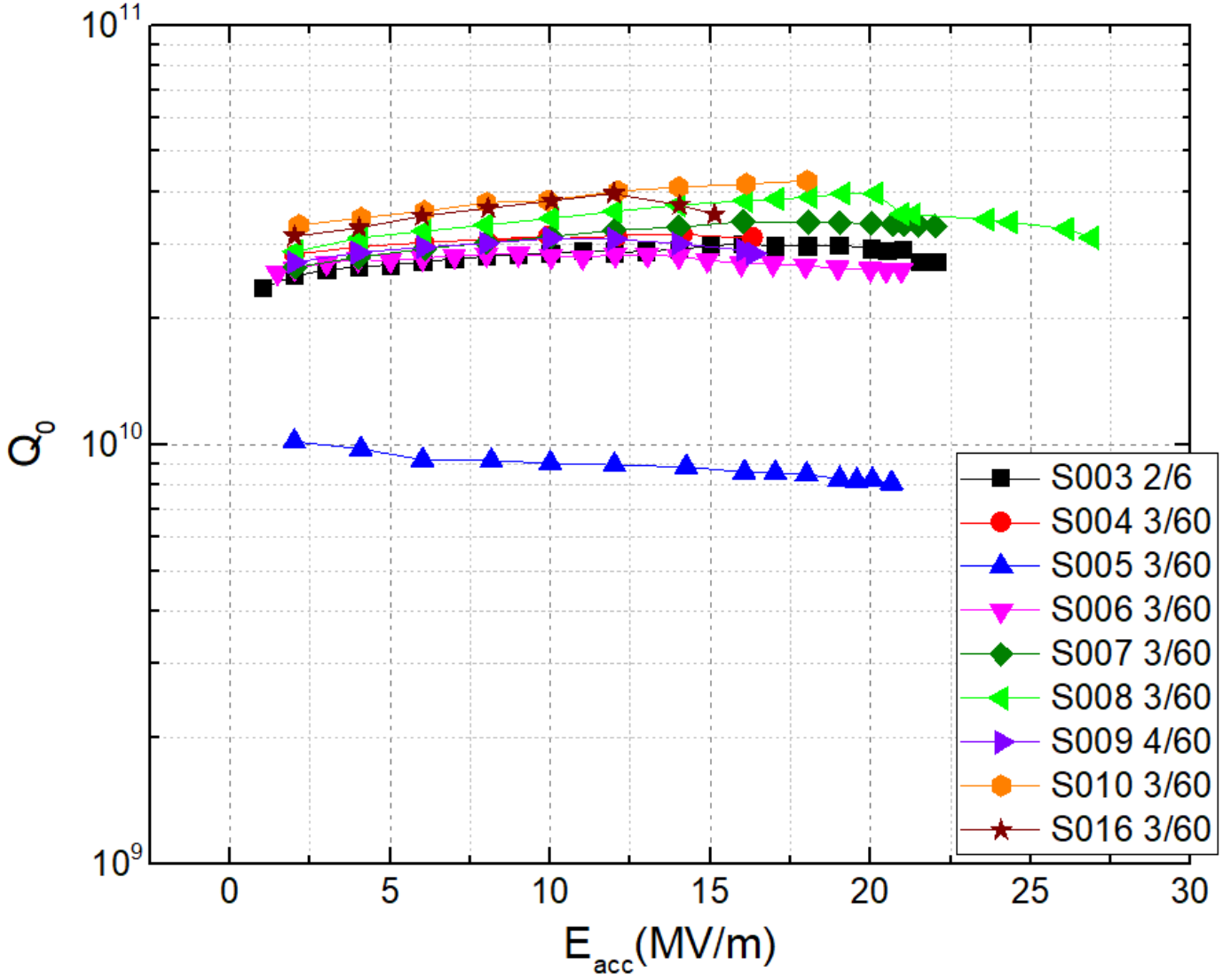
The Equator of cavity after EP

N-doping of 1.3GHz 1-cell cavity at IHEP

Cavity ID	Recipe of N-doping: EP/BCP+N-doping + EP	Best Baseline Result E_{max}/Q_0@16MV/m	N-doping Result E_{max}/Q_0@16MV/m
S003	EP30+2/6-8um	32.5/1.55e10	22.1/3.0e10
S004	EP30+3/60-9.4um	45.6/1.98e10	16.3/3.1e10
S005	EP28+3/60-9.6um	35.5/2.85e10	20.7/8.6e9
S006	EP20+3/60-12um	37/1.34e10	21/2.71e10
S007	EP30+3/60-10.4um	39.6/2.0e10	22.0/3.4e10
S008	EP20+3/60-9.3um	42.3/1.8e10	26.9/3.4e10
S009(LG)	BCP30+4/60-5.9um+HF/HNO3	28.9/1.44e10	16.4/2.9e10
S010(LG)	BCP30+3/60-9.4um	27.2/1.57e10	18.0/4.2e10
S0016	EP20+3/60-9um	33/1.79e10	15.1/NULL
S0017	EP25+3/60-9.3um	44/2.0e10	23.8/2.5e10

N-doping results of 1.3GHz 1-cell cavity

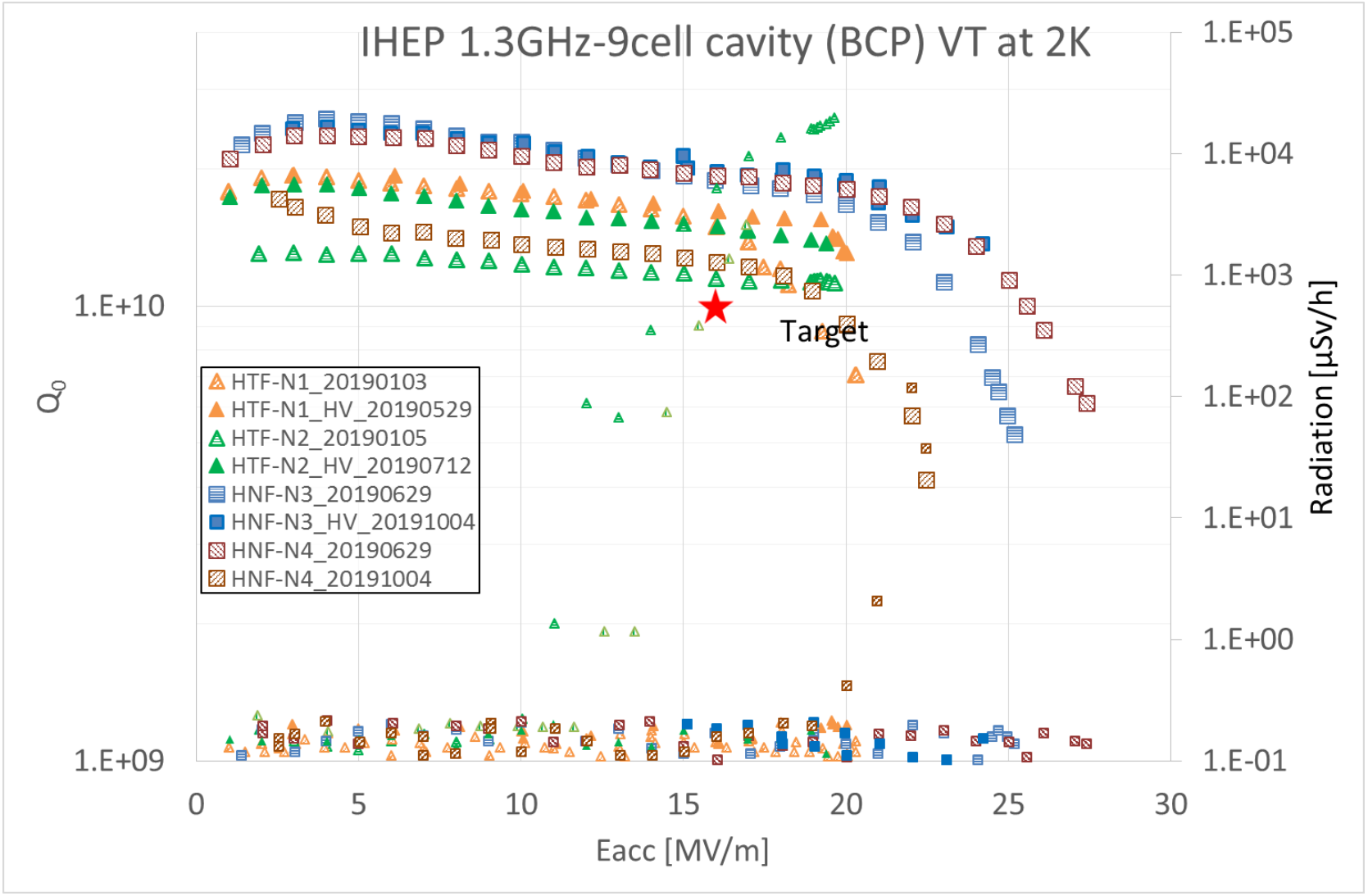
After N-doping：there are 6 1.3GHz 1-cell cavities exceeding the design target of LCLS-II （2.7E10 16MV/m); the Q value of #S008 cavity reach 3.3E10@26MV/m, 。



1.3GHz 9-cell cavity

Eight 9-cell cavities were already made, in which four BCP cavities were vertical tested w&w/o the helium vessel.

Baseline Results of 1.3GHz 9-cell Cavities w&w/o Helium Vessel

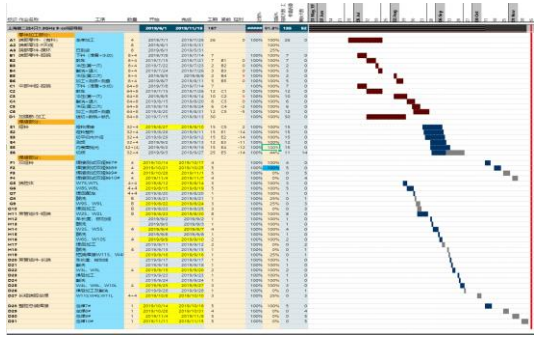


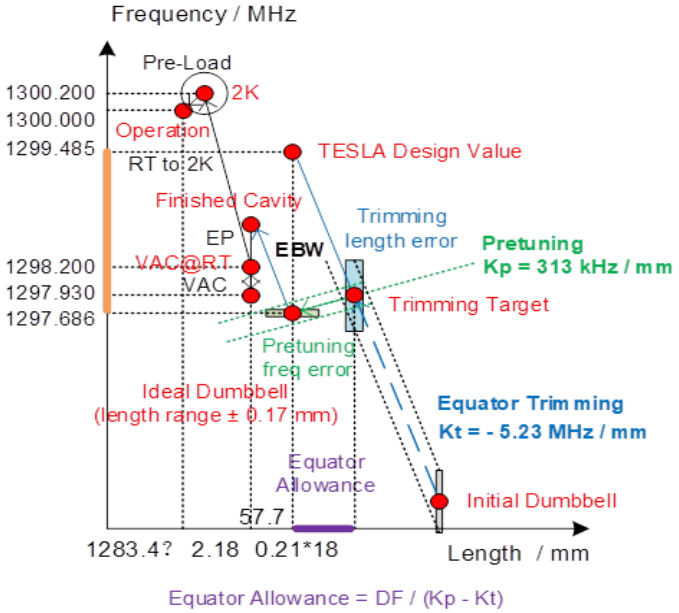
Only BCP!

Cavity Quality Control

- Cavity database and QC documents (*on cloud*). Use ten 9-cell cavities to build the best architecture and integrate into one database for mass production.
- Comprehensive records of fabrication, processing and testing. More than 10000 data and images per cavity.
- Precise control of frequency, shape, length, eccentricity and field flatness through the whole cavity life cycle.

Cavity QC Documents and Databases
1. Half cell, dumbbell, end group records & trimming
2. 9-cell RF and mechanical control and records
3. 9-cell pretuning and field flatness
4. Processing and assembly procedures & parameters
5. HOM notch tuning at RT
6. Vertical test with passband and OST
7. FM Qe & notch and HOM Qe measurement at 2 K
8. Schedule of fabrication, processing, dressing and testing





RF and Mechanical Quality Control

	Specification	1300-N001	1300-N002	1300-N003	1300-N004
Dumbbell shape error	**≤ +/- 0.5 mm**	± 0.4	± 0.4	± 0.4	± 0.4
Cavity length (after pre-tuning)	**1283.40 +/- 3.0 mm**	1284.55 mm	1283.19 mm	not measured	not measured
Cavity length in helium vessel	**1283.40 +/- 3.0 mm**	1283.56 mm	1282.30 mm	1280.94 mm	to be measured
Eccentricity (radius)	**≤ 0.4 mm**	no adjustment	no adjustment	no adjustment	no adjustment
Frequency bare cavity (vacuum, RT)	**1298.2 +/- 0.1 MHz**	1298.210 MHz	1298.160 MHz	1298.162 MHz	not measured
Frequency bare cavity (2K)	**1300.2 +/- 0.1 MHz**	1300.252 MHz	1300.199 MHz	1300.318 MHz	1300.280 MHz
Frequency dressed cavity (2K)	**1300.2 +/- 0.1 MHz**	1299.870 MHz	1300.018 MHz	1300.062 MHz	**1300.147 MHz**
Field flatness bare cavity	**≥ 95 %**	95%	98%	97%	96%
Field flatness dressed cavity	**≥ 90 %**	85%	94%	98%	98%
Leak rate	**≤ 1.0e-8 Pa l/s**	OK	OK	OK	OK
HOM coupler FM Q_e (2K)	**> 2.7E11**	1.5E12, 3.5E13	3.7E12, 4.7E11	1.6E11, 2.1E12	2.7E14, 1.9E12
Bare cavity gradient (BCP)	**> 19 MV/m**	20 MV/m	19.5 MV/m	25 MV/m	26.5 MV/m
Bare cavity Q_0 (BCP)	**> 1.0×10^{10} @16 MV/m**	1.50E+10	1.20E+10	1.90E+10	1.90E+10
Dressed cavity gradient (BCP)	**> 19 MV/m**	20 MV/m	19.5 MV/m	23.2 MV/m	17 MV/m (FE limit)
Dressed cavity Q_0 (BCP)	**> 1.0×10^{10} @16 MV/m**	1.50E+10	1.40E+10	1.90E+10	1.0E10

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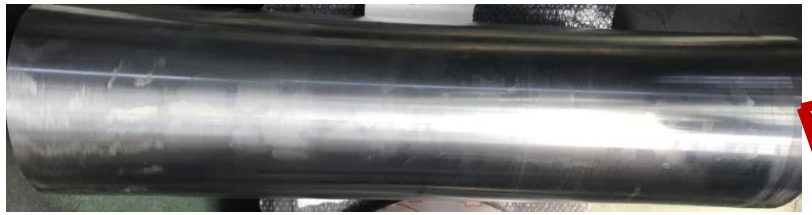
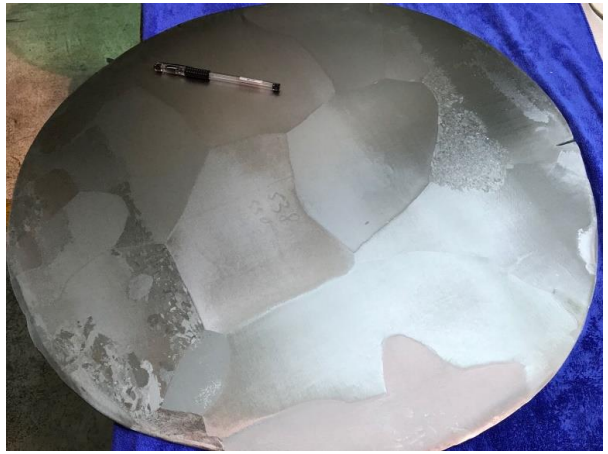
3. High Q&G activity of 650 MHz LG Cavities
4. Summary

650 MHz 1-cell cavity (large grain)

Large grain cavity may have higher Q and gradient than fine grain. But it's much more difficult to fabricate : (1)easily crack at grain boundary; (2) the large-grain Nb sheet is too large (Φ540mm), the quality of the sheet is hard to control.



Nb ingot (Φ280mm)



Grain crack

Φ540mm large-grain Nb sheet for 650 MHz 1-cell cavity

650 MHz 2-cell (fine grain)

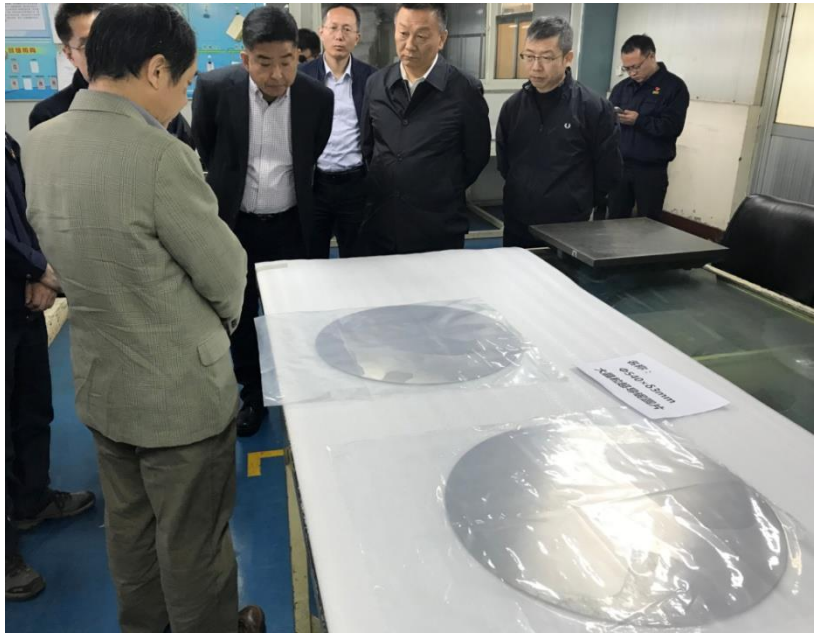
1.3 GHz 9-cell (fine grain)

1.3 GHz 9-cell (large grain, PKU)

650 MHz 1-cell cavity (large grain)

To get the job done, OTIC made a new Nb ingot (Φ480mm) for us, which was used for half cells of 650MHz cavity. Many half cells were broken during deep-drawing.

Nb ingot (Φ480mm)



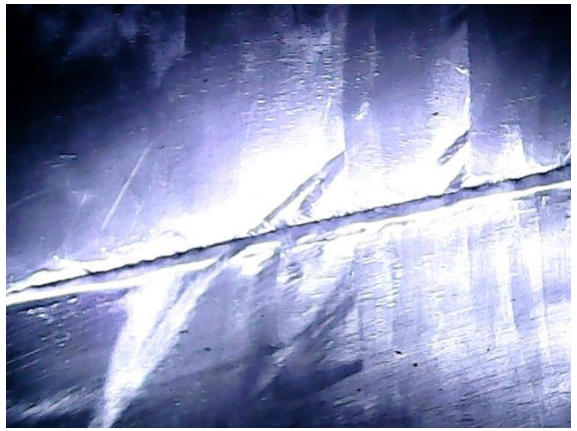
Large grain Nb sheets made by OTIC

Half-cells broke after deep-drawing

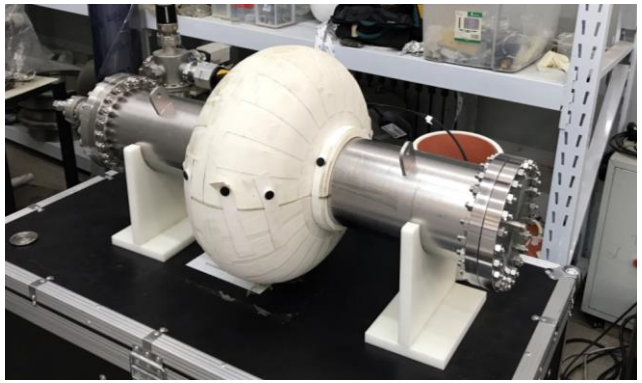
650 MHz 1-cell cavity (large grain)

- Four 650 MHz 1-cell LG cavities were completed in Oct, 2020. Both the outer and inner surface of cavities are poor.
- Two cavities have finished post processing , include BCP, annealing, HPR, 120 C baking, etc.

Four cavities



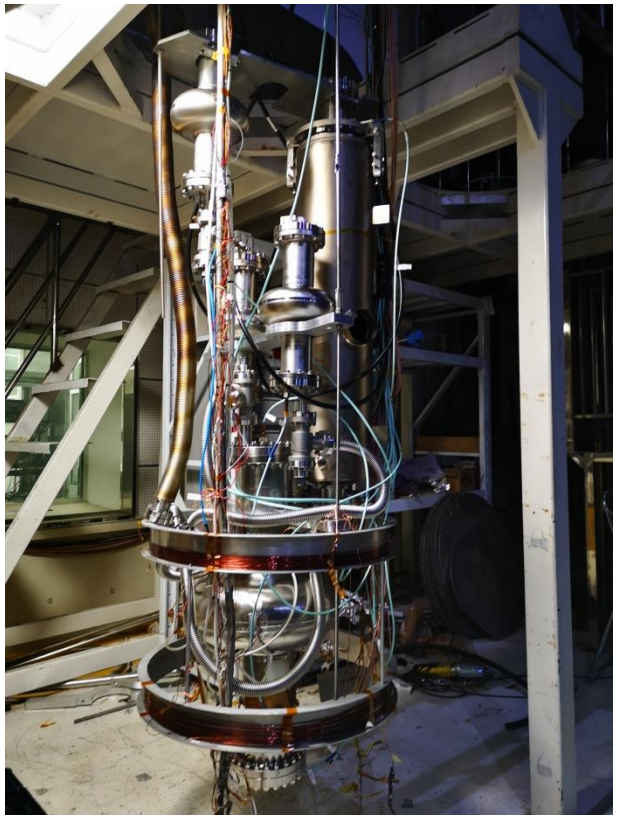
BCP



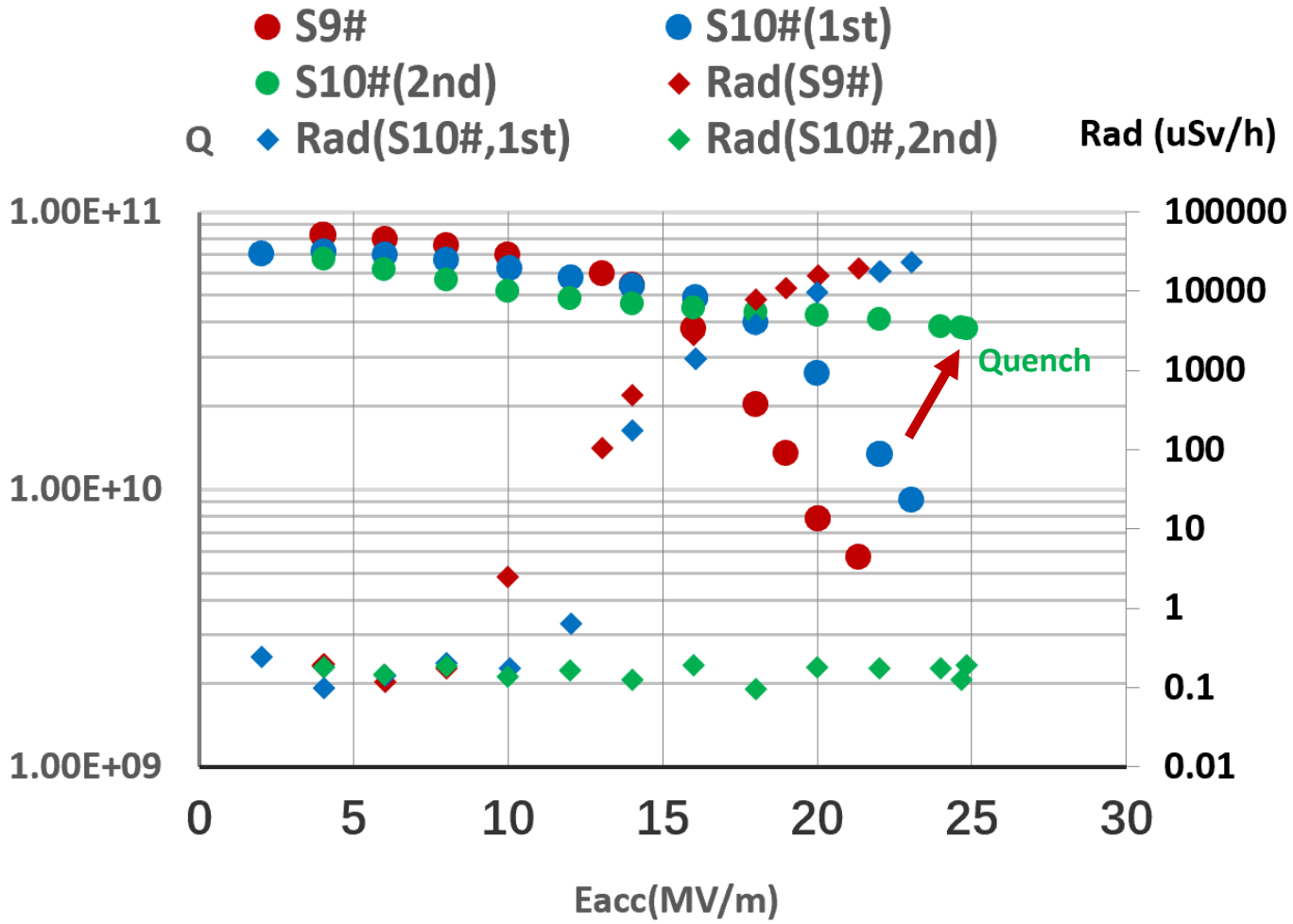
120 C baking

Vertical test of 650MHz 1-cell LG cavity

- Several vertical tests have been carried out during Nov and Dec, 2019.
- The results are not so good because of the poor inner surface.



Vertical test of 650 MHz 1-cell LG cavity, 1.3 GHz 9-cell cavity with Helium Vessel and 3 1.3 GHz 1-cell cavities (20191109)



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4. Summary: 1. There is a desperate need to find the reason why the Eacc of 1-cell cavity after N-doping can not beyond 30MV/m, almost half of baseline value;

2. N-doping/ Mid-T baking will be applied to both 1-cell and 9-cell cavities soon.

Thanks for your attention!