Institute of High Energy Physics
Chinese Academy of Sciences

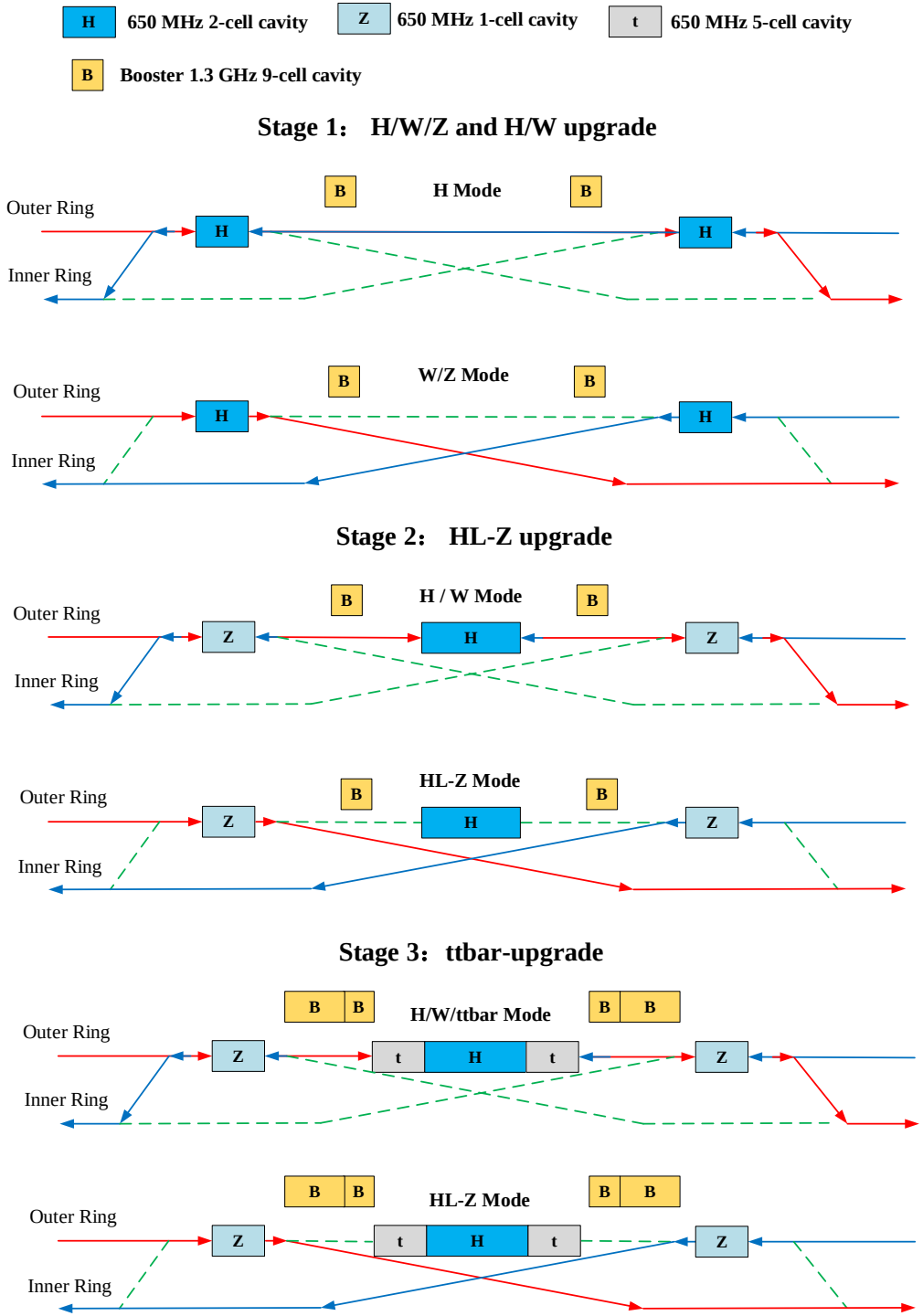
Circular Electron Positron Collider

Status of the high Q R&D for CEPC SCRF cavities

Peng Sha (IHEP)

The 2021 International Workshop on the
High Energy Circular Electron Positron Collider

New RF Staging & By-pass Scheme for CEPC



Stage 1 (H/W run for 8 years): Keep CDR RF layout for H(HL-H)/W and 50 MW upgrade. Common cavities for H. Separate cavities for W/Z. Z initial operation for energy calibration and could reach CDR luminosity. **Minimize first phase construction cost and hold Higgs priority**.

Stage 2 (HL-Z upgrade): Move Higgs cavities to center and add high current Z cavities. **By-pass low current H cavities**. International sharing (modules and RF sources): Collider + 130 MV 650 MHz high current cryomodules.

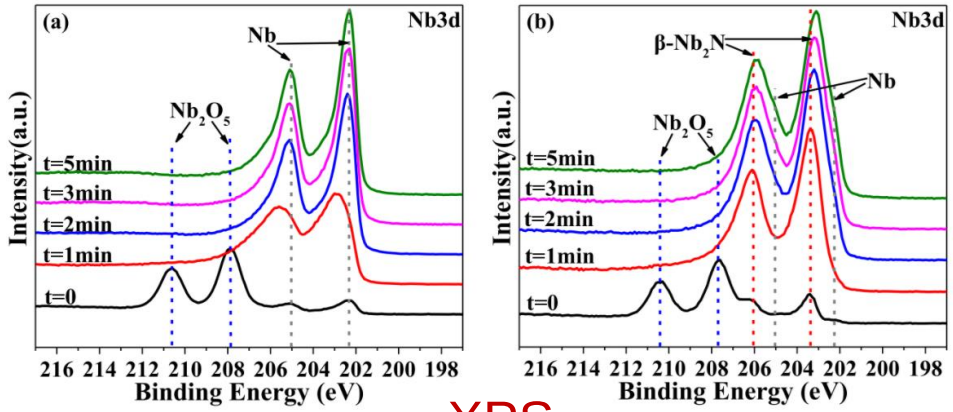
Stage 3 (ttbar upgrade): add ttbar cavities (international sharing): Collider + 7 GV 650 MHz 5-cell cavity, Booster + 6 GV 1.3 GHz 9-cell cavity. Both low current, high gradient, high Q. Nb_3Sn@4.2 K or others.

Outline

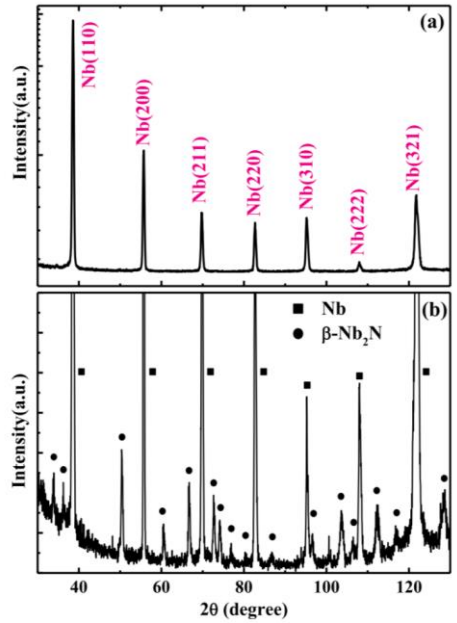
- **1.3 GHz 9-cell cavity**
- 650 MHz 1-cell/2-cell cavity
- Nb_3Sn cavity
- Conclusion

1.3 GHz 1-cell cavities nitrogen doped

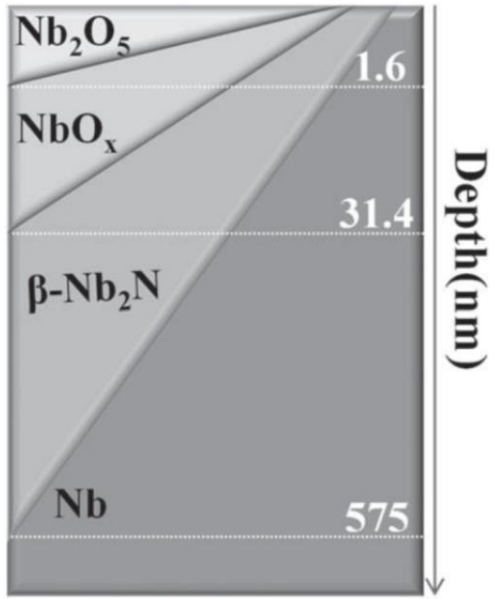
- “3/60” recipe is adopted for nitrogen doping. 2.6E10@30MV/m has been achieved for 1.3 GHz 1-cell.



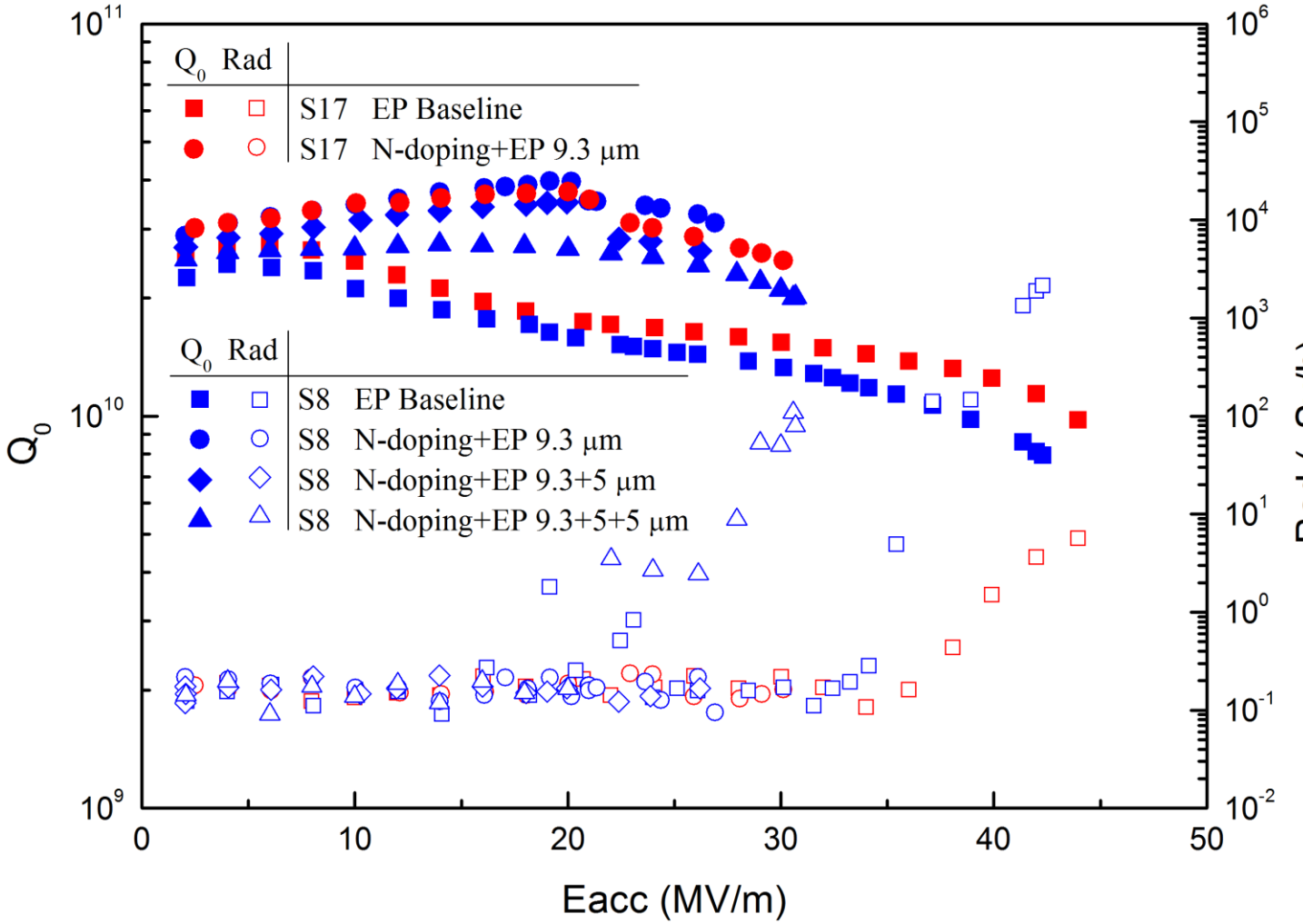
XPS



XRD



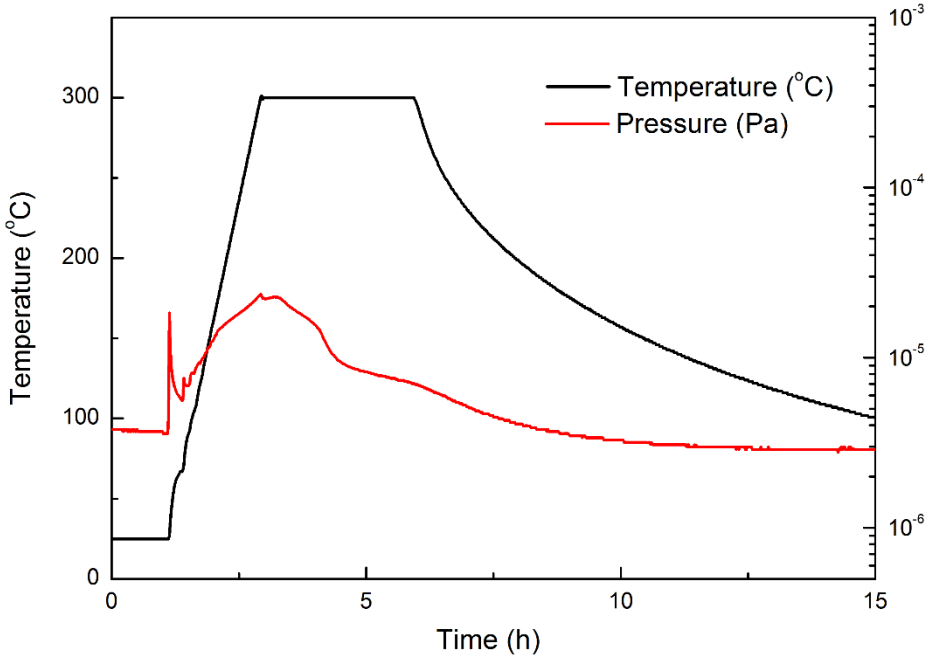
Depth profile



Vertical test results of 1.3 GHz 1-cell cavities

Mid-T furnace baking of 1.3 GHz 9-cell cavities

- Six 1.3 GHz 9-cell cavities (N5~N10) received mid-T furnace baking (300 C 3h).
- One 9-cell cavity (N9) adopted the simplified recipe, which cancelled light Electro-polishing.

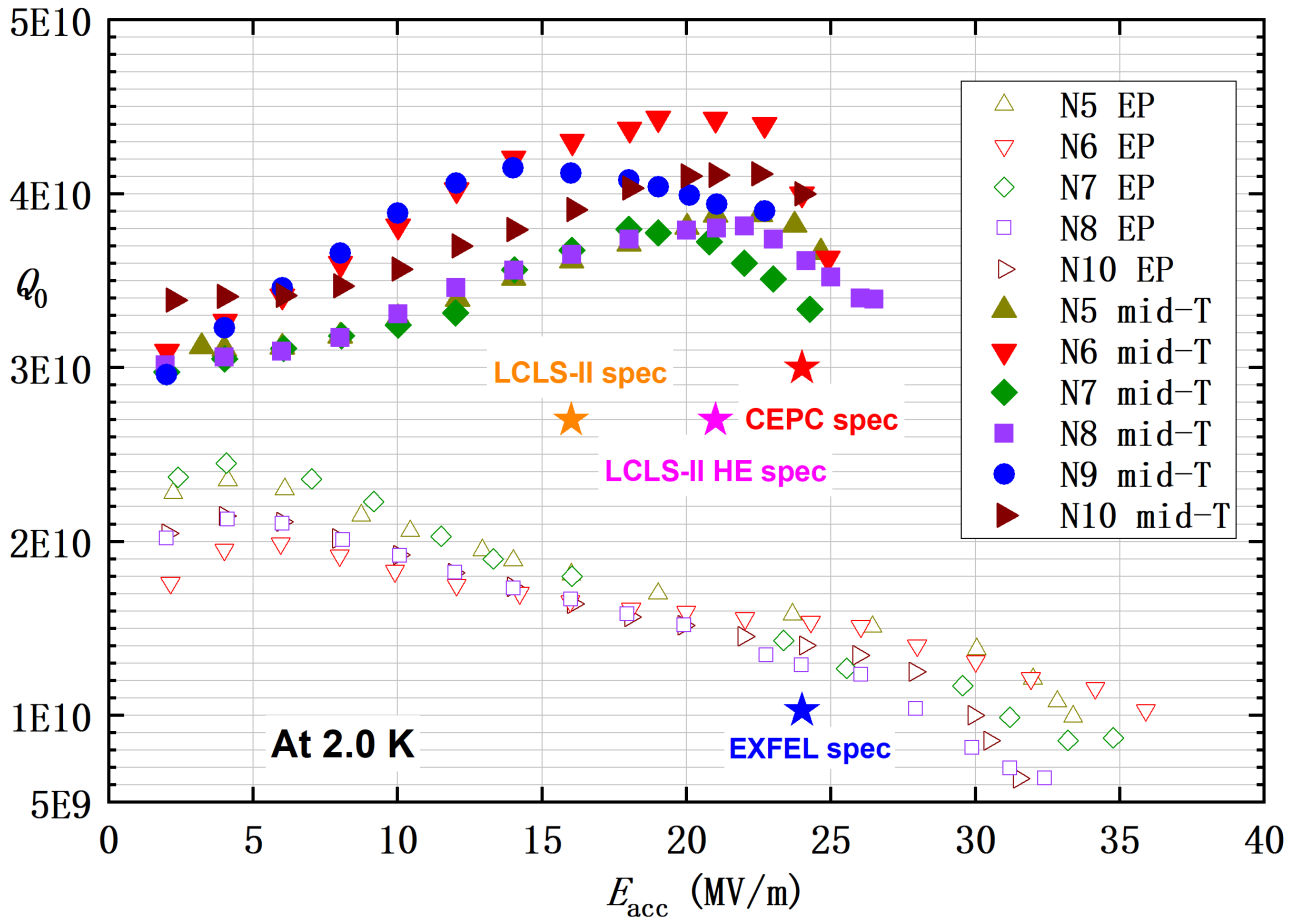


Process of N5, N6, N7, N8, N10	Process of N9
Bulk EP	Bulk EP
800 °C 3 h	900 °C 3 h
Light EP	Exposure to air
Vertical test	Mid-T furnace baking
900 °C 3 h	Vertical test
Exposure to air	
Mid-T furnace baking	
Vertical test	

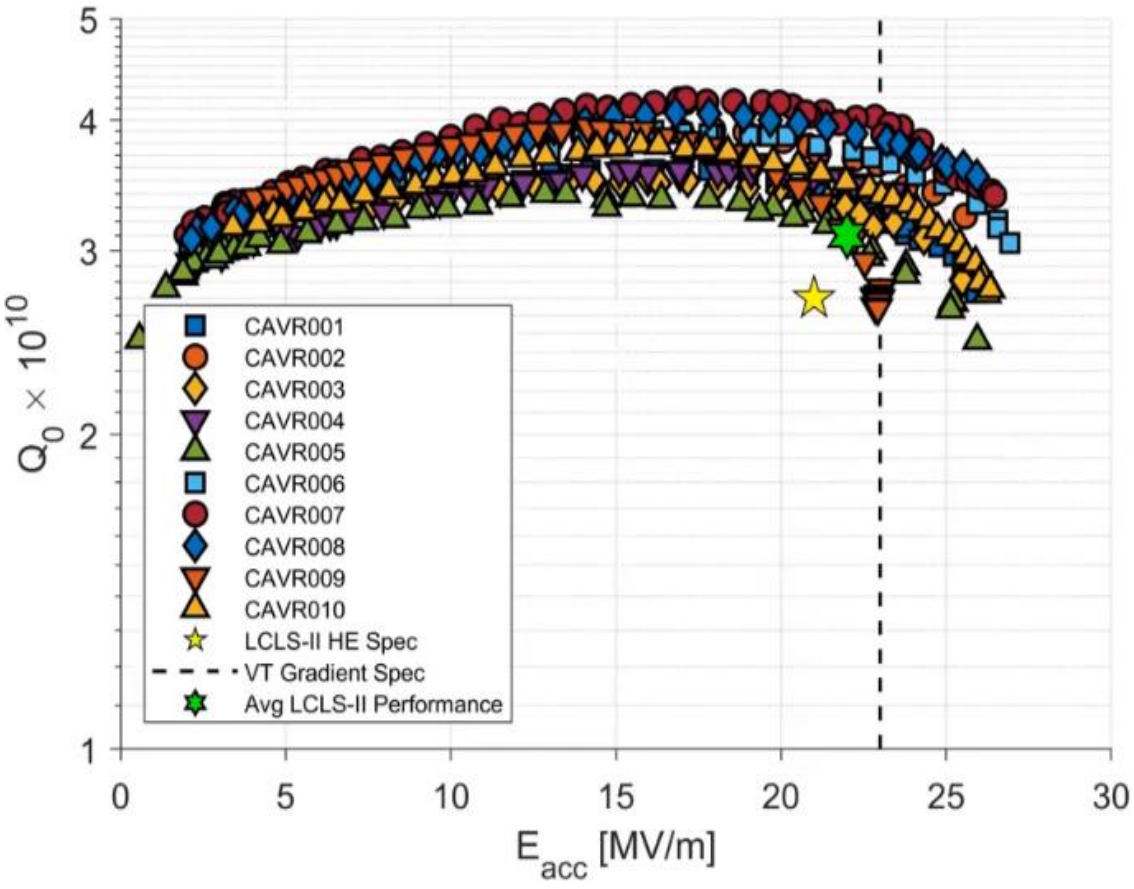
Treatments for 1.3 GHz 9-cell cavities mid-T furnace baked

Vertical test results of 9-cell cavities

- After mid-T furnace baking, all the six 9-cell cavities demonstrated high *Q* (3.5–4.4E10 @ 16–24 MV/m), which is as good as LCLS-II HE.

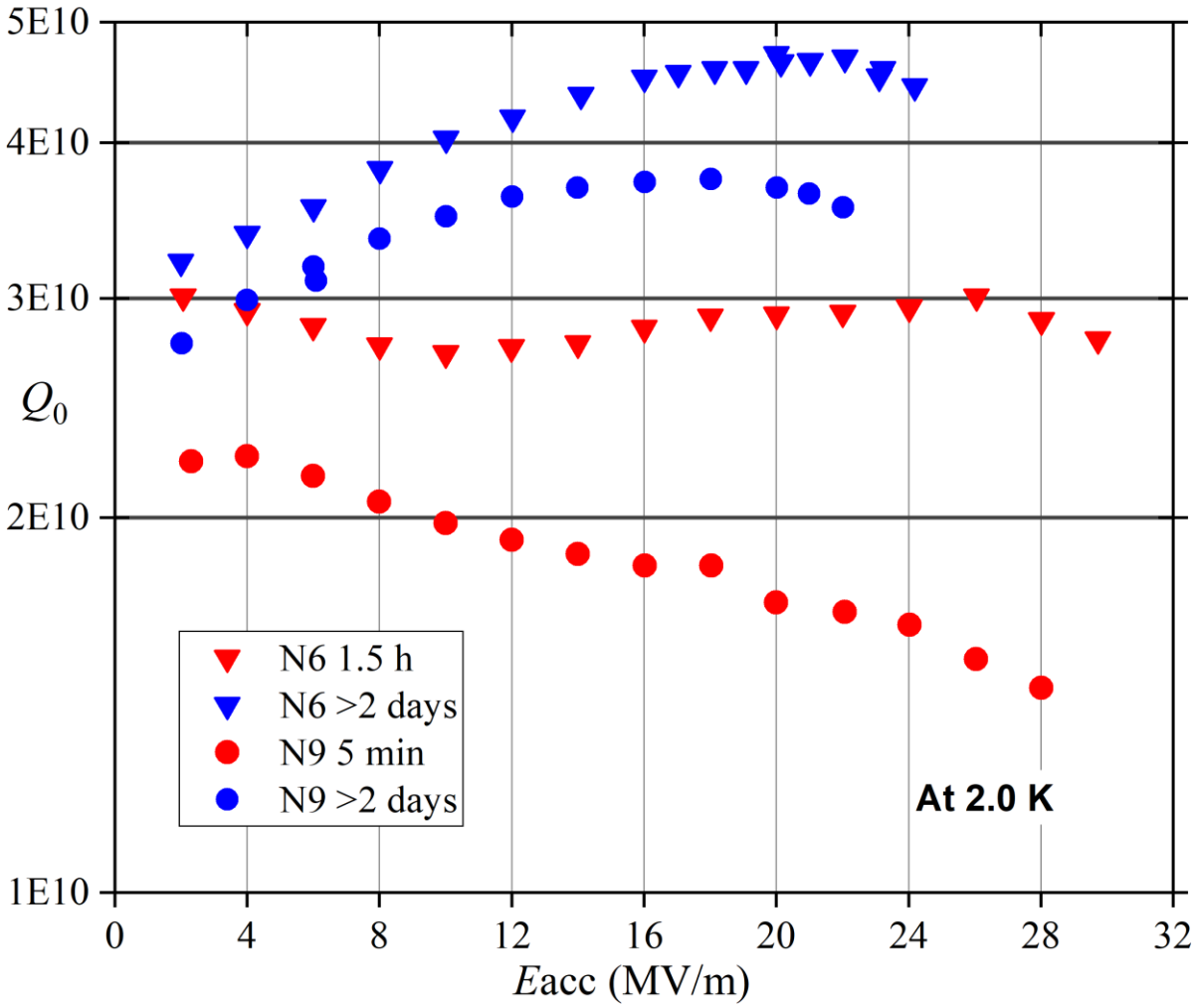


1.3 GHz 9-cell cavities mid-T furnace baked at IHEP

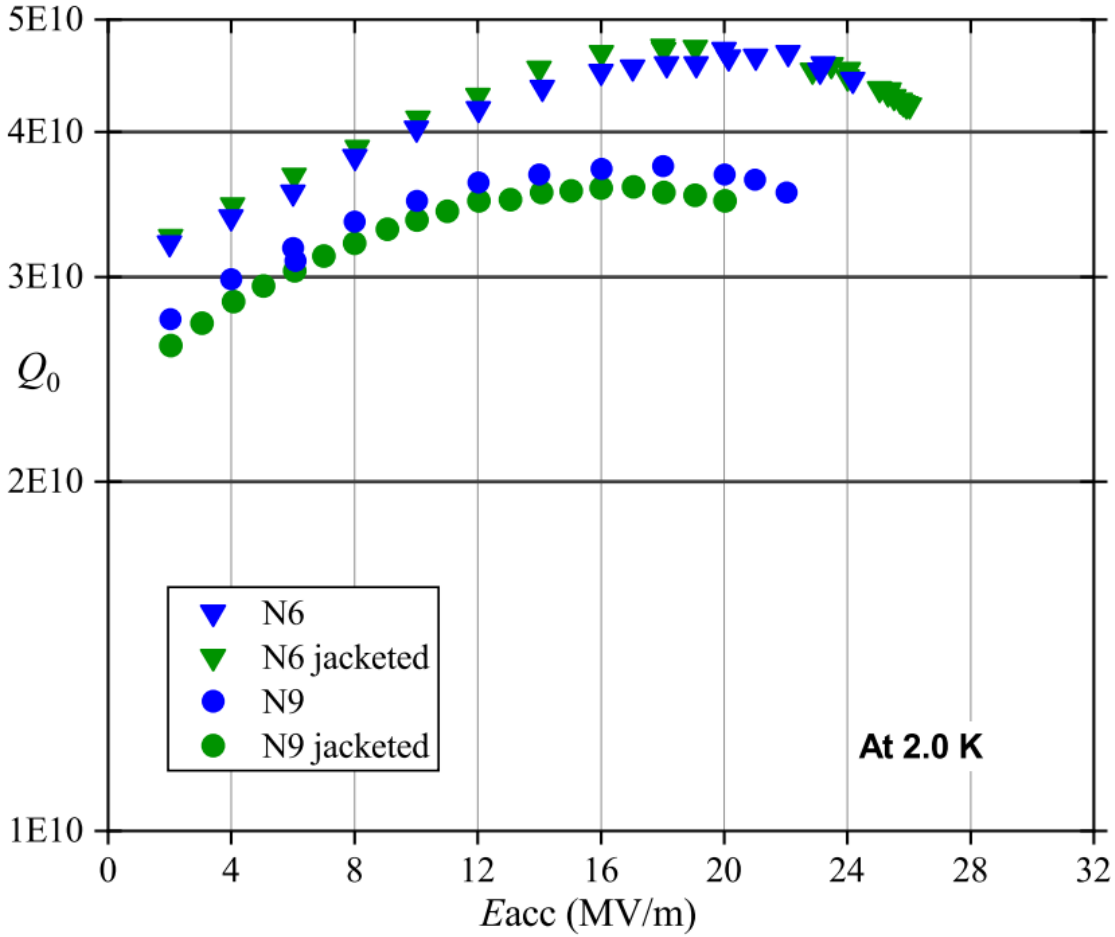


1.3 GHz 9-cell cavities N-doped for LCLS-II HE

Comparisons



Duration of exposure to air between the high-temperature annealing and mid-T furnace baking was optimized.



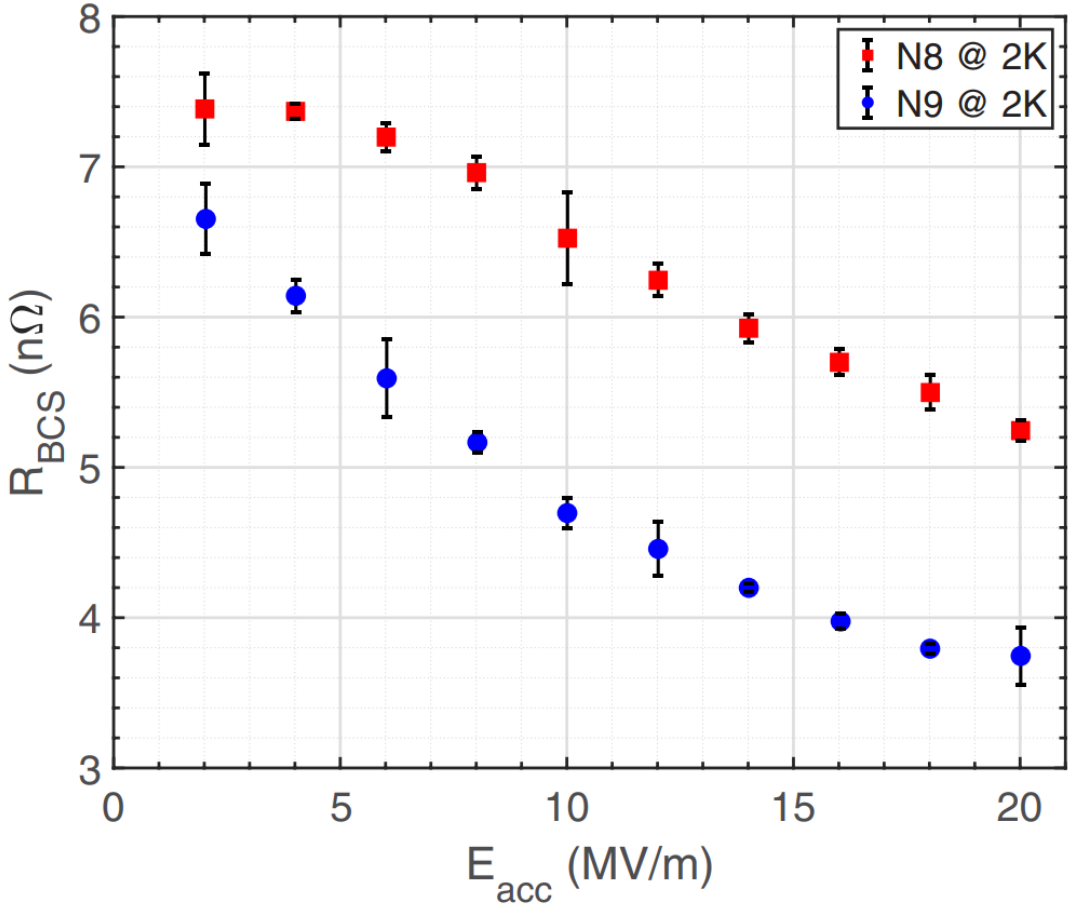
Performance of 9-cell cavities jacketed did not degrade, enabling the integration of the cavities into a cryomodule.

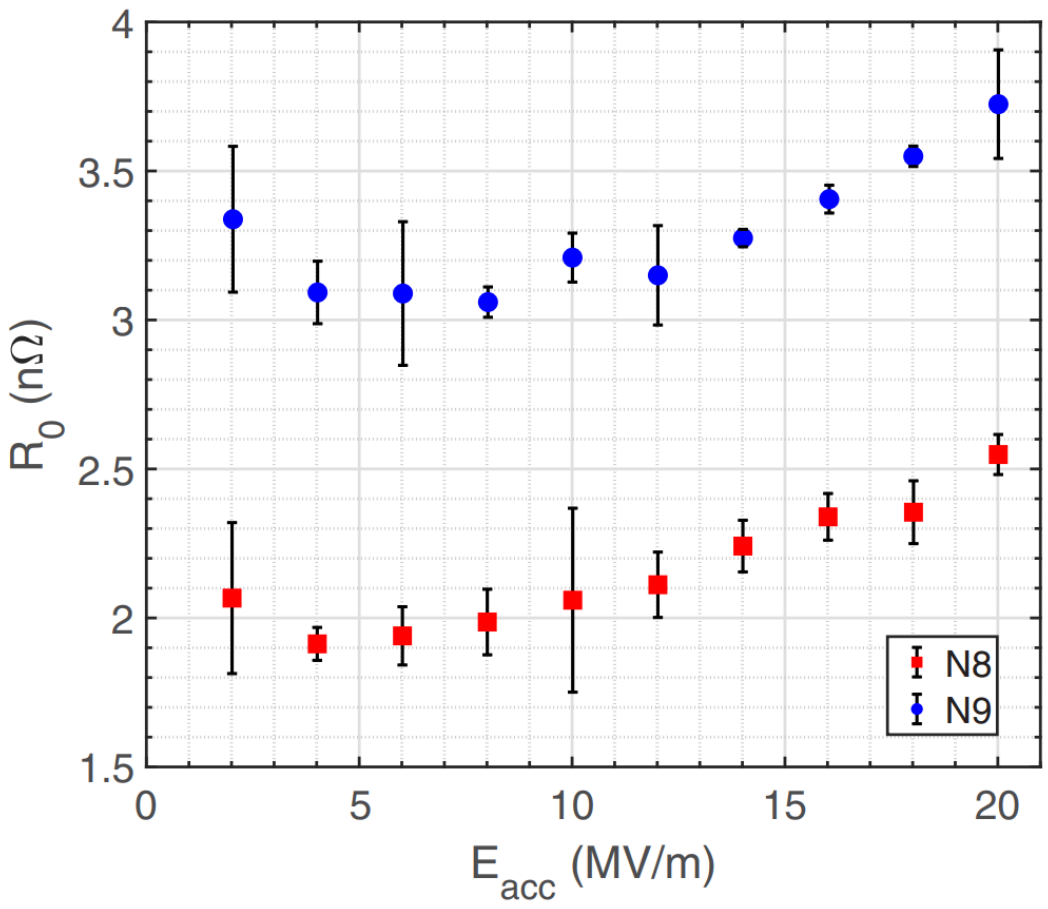
What does mid-T furnace baking do?

- The high Q and anti-Q-slope behavior of mid-T furnace baked cavities is attributed to the BCS resistance, similar to the case of nitrogen doping.

$$R_S = R_{BCS} + R_0$$

$$R_{BCS} = A\frac{f^2}{T}\exp\left(-\frac{\Delta(T)}{kT}\right)$$





Summary of mid-T furnace baking with 9-cell cavities

- It could be used not only for CEPC, but also many FELs (LCLS-II, SHINE, Dalian FEL, Shenzhen FEL…)
- Details: F. He, W. Pan, P. Sha et al, Supercond. Sci. Technol. 34 095005

IOP Publishing Superconductor Science and Technology
Supercond. Sci. Technol. 34 (2021) 095005 (7pp) https://doi.org/10.1088/1361-6668/ac1657

Medium-temperature furnace baking of 1.3 GHz 9-cell superconducting cavities at IHEP

Feisi He[1,2,3,4], Weimin Pan[1,2,3,4,*], Peng Sha[1,2,3,4,*], Jiyuan Zhai[1,2,3,4], Zhenghui Mi[1,2,3,4], Xuwen Dai[1,3], Song Jin[1,2,3,4], Zhanjun Zhang[1,3], Chao Dong[1,2,3], Baiqi Liu[1,2,3], Hui Zhao[1,3], Rui Ge[1,2,3,4], Jianbing Zhao[1,3], Zhihui Mu[1,3], Lei Du[1,2,3], Liangrui Sun[1,2,3], Liang Zhang[1,3], Conglai Yang[1,3] and Xiaobing Zheng[1,3]

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The impressive results on **single cells at 650MHz** and **9-cell at 1.3 GHz** demonstrated that the SCRF team has reached a **world-class level** on superconducting cavity fabrication and surface treatments.

2021 Second CEPC IARC Meeting Report

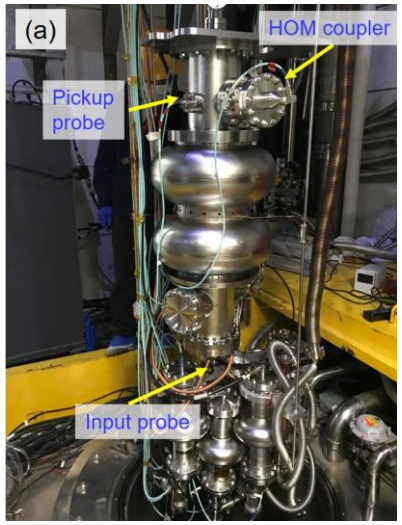
Outline

- 1.3 GHz 9-cell cavity
- **650 MHz 1-cell/2-cell cavity**
- Nb_3Sn cavity
- Conclusion

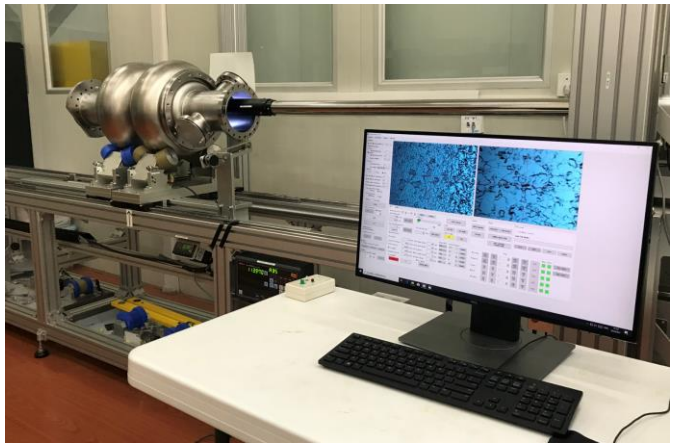
650 MHz 2-cell cavities BCP processed (1)

- Three 650 MHz 2-cell cavities were fabricated, buffered chemical polished (BCP) and tested, which all exceeded 3E10@20MV/m.

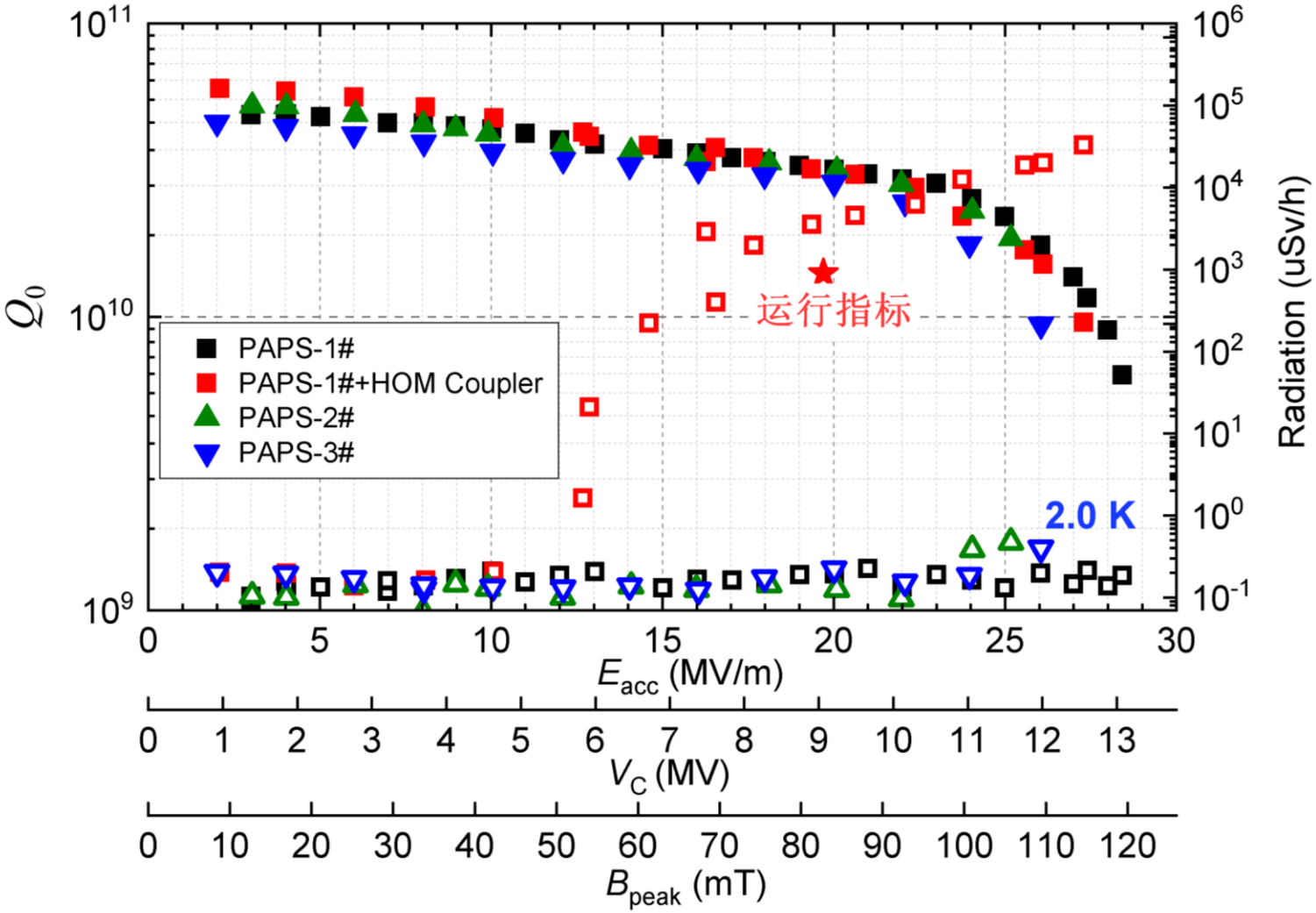
BCP



Vertical test



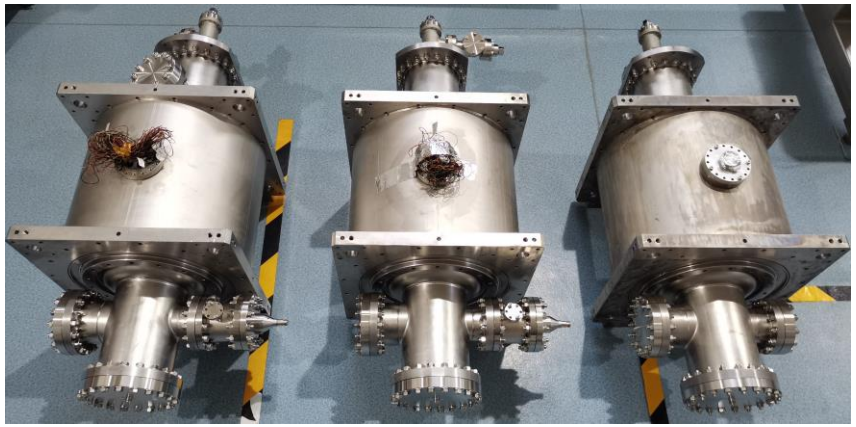
Inspection



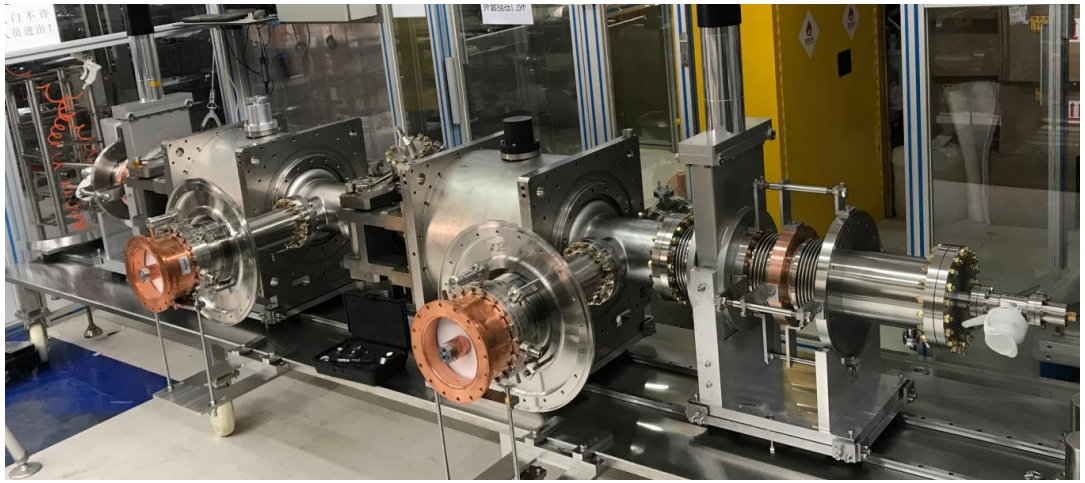
Vertical test results of 650 MHz 2-cell cavities

650 MHz 2-cell cavities BCP processed (2)

- All the three 2-cell cavities were welded with helium vessel, two of which have been integrated into a 650 MHz test cryomodule at PAPS.



2-cell cavities jacketed

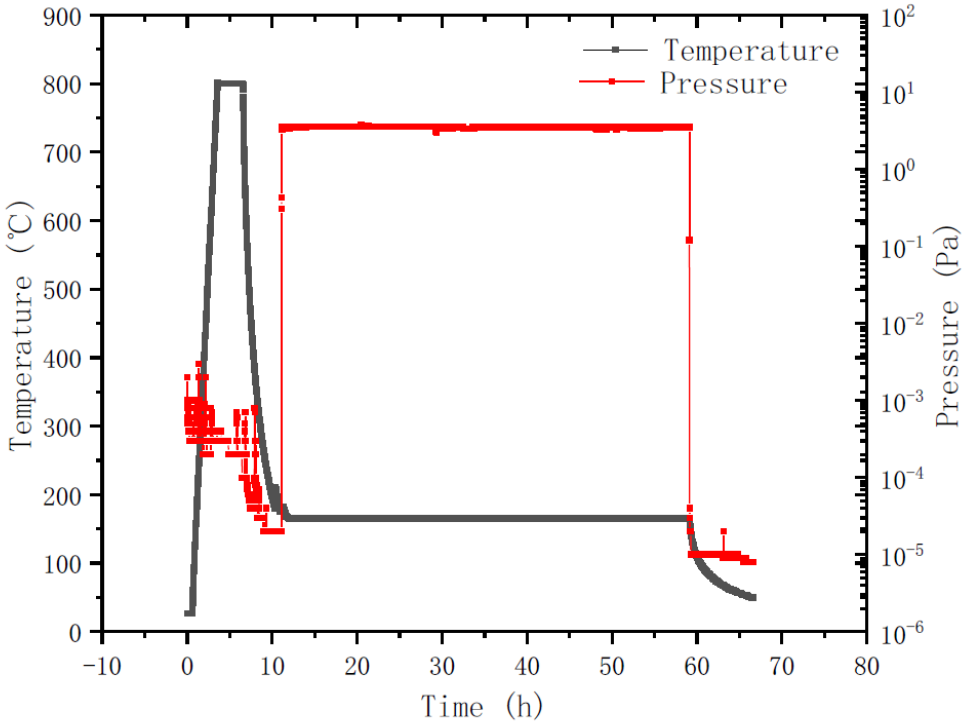


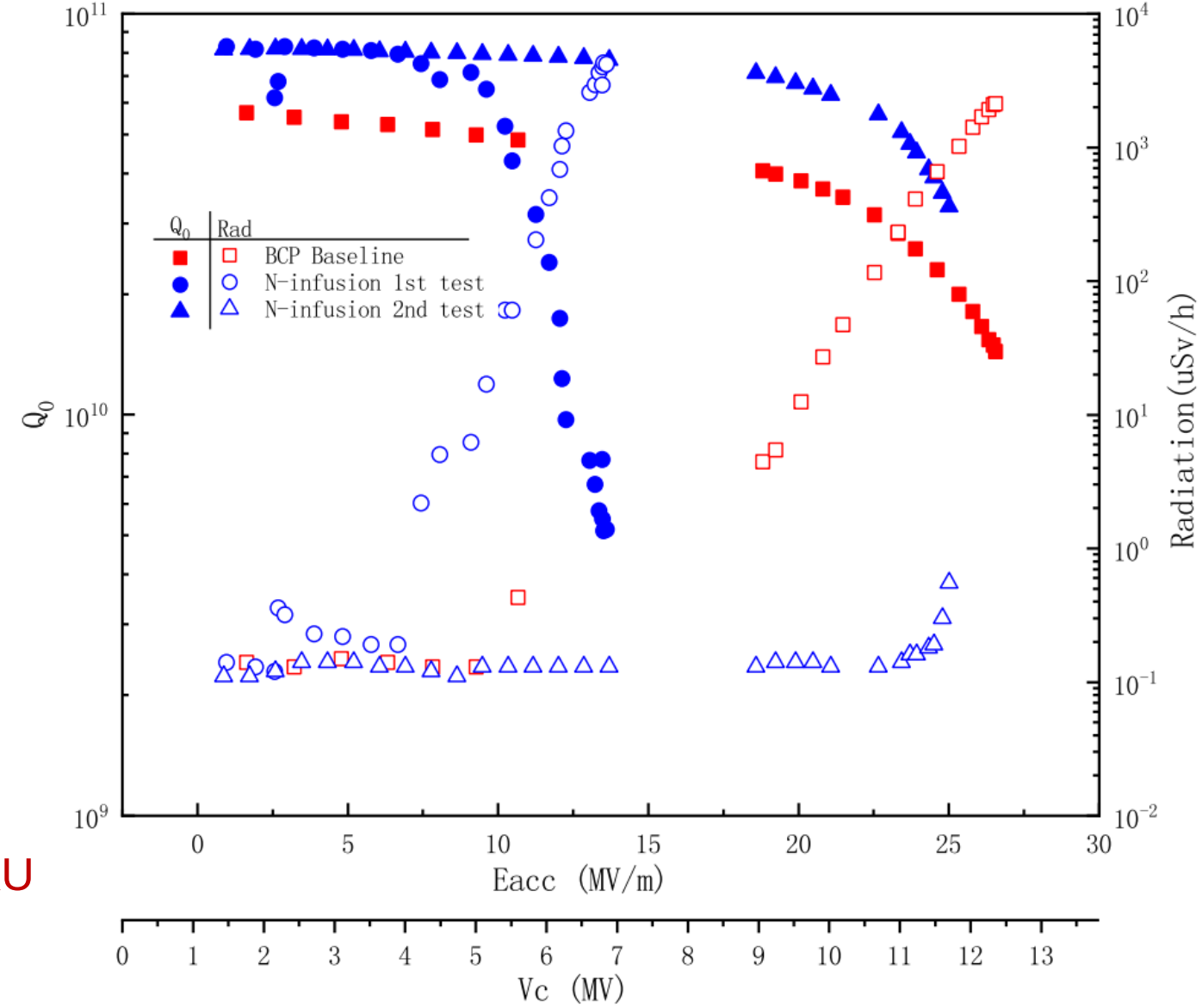
Cavity string

650 MHz test cryomodule for CEPC

650 MHz 2-cell cavity BCP + N-infusion

- Another 650 MHz 2-cell cavity is nitrogen infused at 165 C for 48 h with BCP baseline.
- 6E10@22MV/m was achieved.

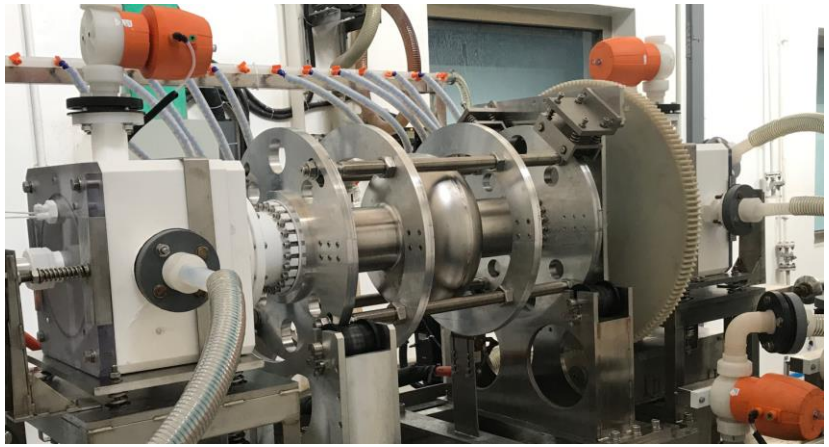




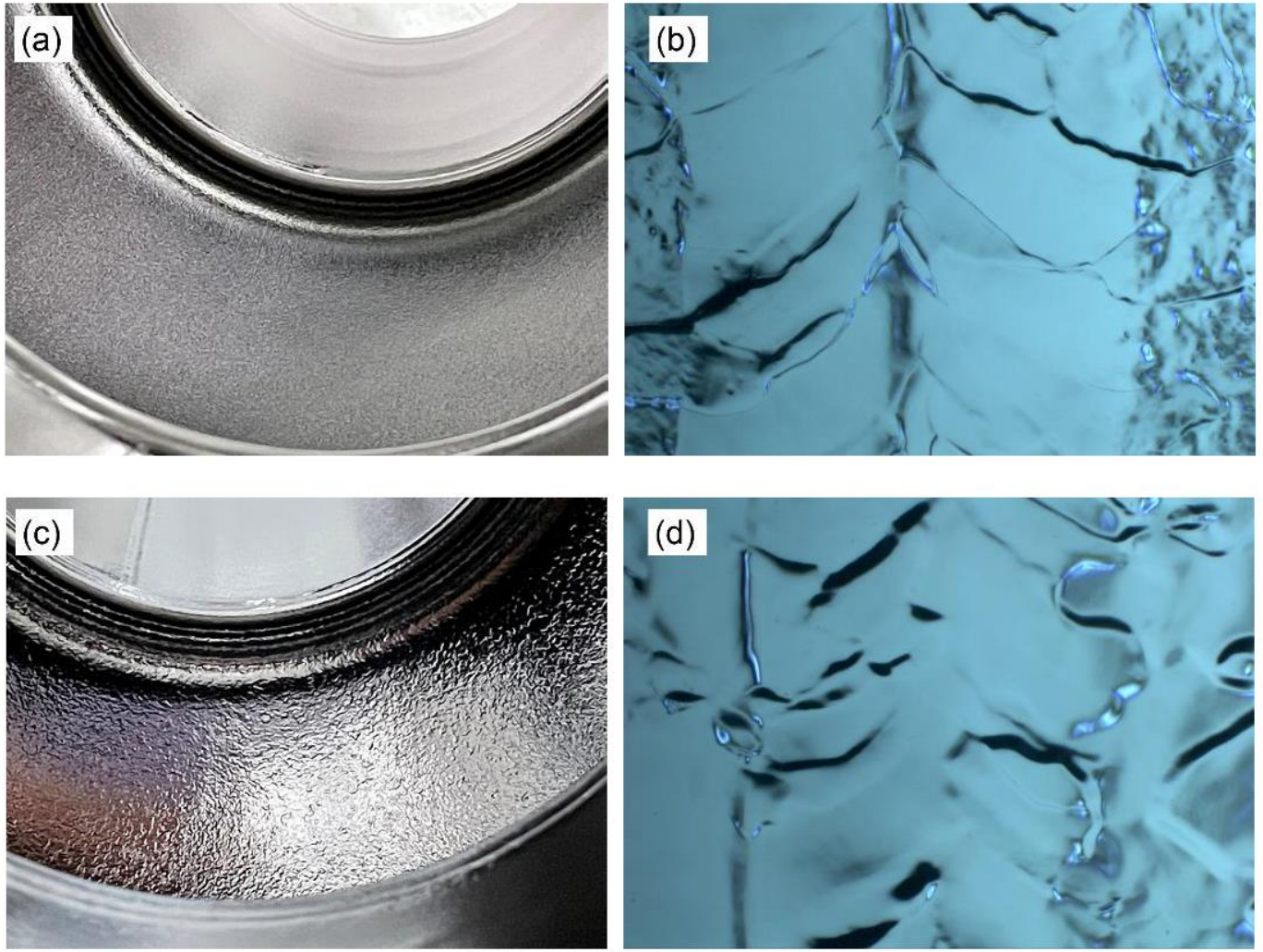
Courtesy of Jiankui Hao, PKU

650 MHz 1-cell cavities EP processed (1)

- Firstly, two 1-cell cavities (650S4 and 650S5) were processed with BCP and tested.
- Afterwards:
- 650S4 received light EP, annealing and light EP again.
- 650S5 received only bulk EP with temperature < 25 °C, which restrained absorption of hydrogen by the niobium cavity. Thus, annealing was omitted, which would be evaluated by the vertical test.



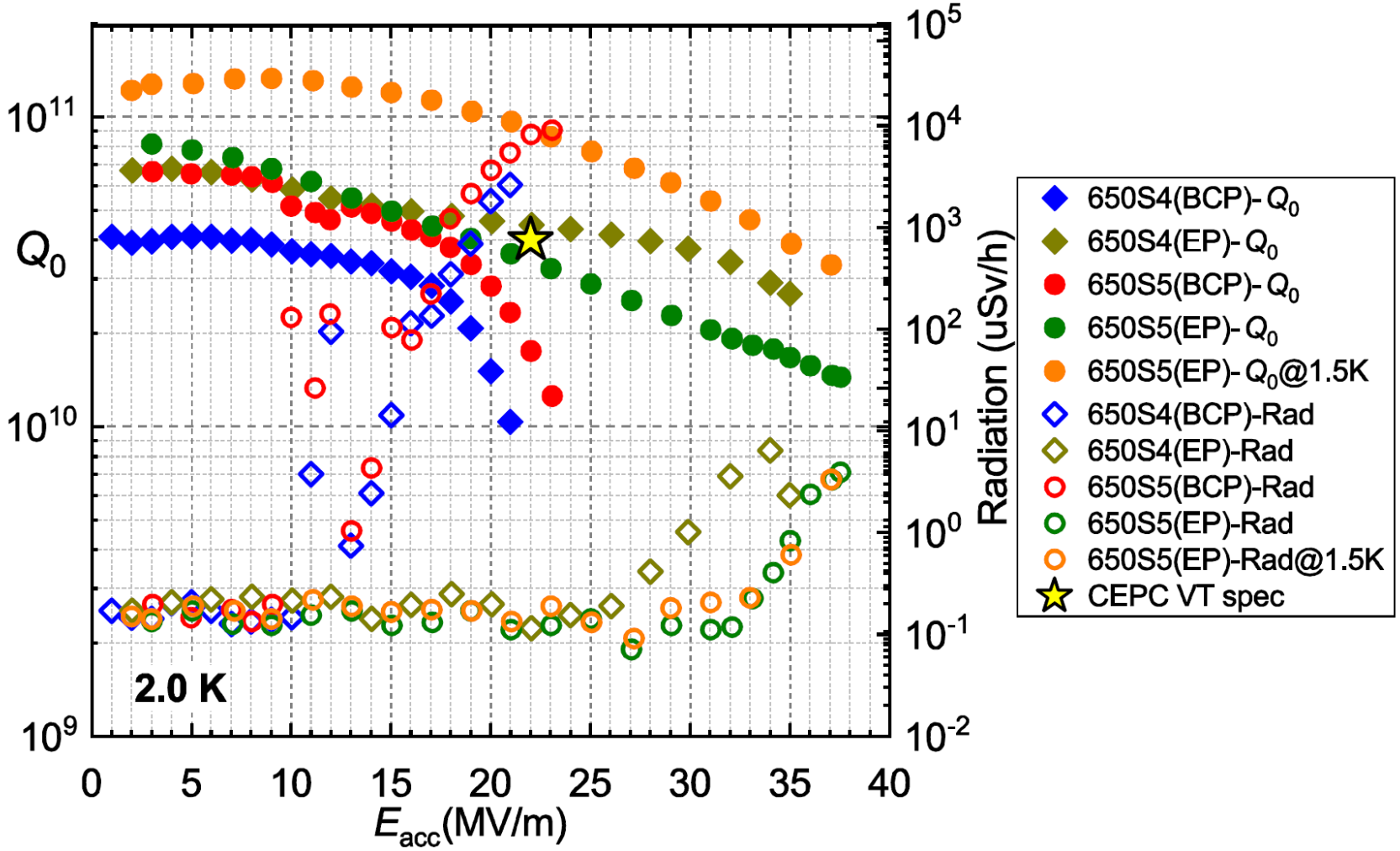
EP of 650 MHz 1-cell cavity



Images of 650-MHz 1-cell cavities EP processed. (a) cell of 650S4, (b) equator of 650S4 by inspection camera, (c) cell of 650S5, and (d) equator of 650S5 by inspection camera.

650 MHz 1-cell cavities EP processed (2)

- Both cavities exceeded 35 MV/m, which is state-of-the-art gradient for large elliptical cavities (< 1 GHz).
- 650S4: 4.5E10@22.0 MV/m.
- Q_0 of 650S5 is 3.4E10@22.0 MV/m, which is a little lower than 650S4 above 20 MV/m. The *Q*-slope phenomenon of 650S5 at 1.5 K is similar as that at 2.0 K. The relatively low Q_0 of 650S5 may be resulted from the cancellation of annealing.

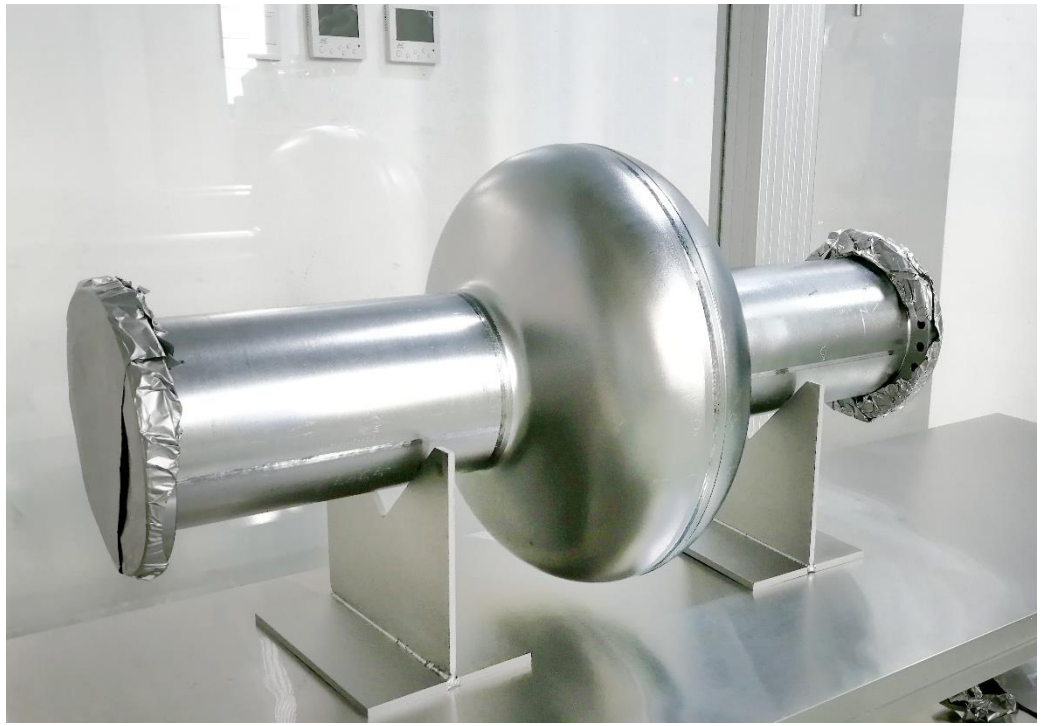


Comparison of 650 MHz 1-cell cavities processed with BCP and EP.

Mid-T furnace baking of 650 MHz 1-cell cavities (1)

- After EP process, 650S4 and 650S5 received mid-T furnace baking at PAPS.
  - 650S4: 300 C 3 h
  - 650S5 adopted the simplified recipe: 900 C 3h + exposure to air for 3 days + 300 C 3 h

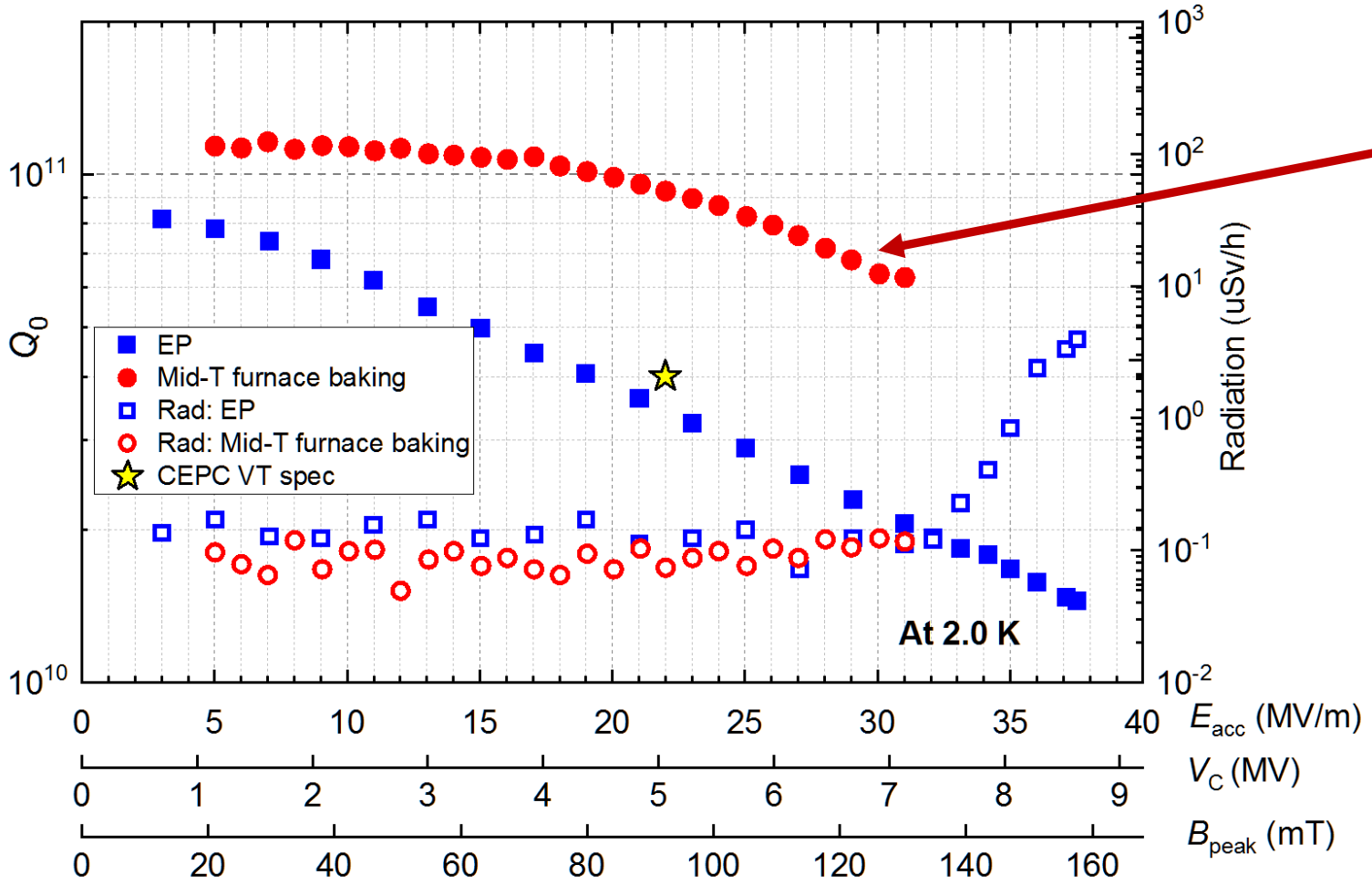
Mid-T furnace baking

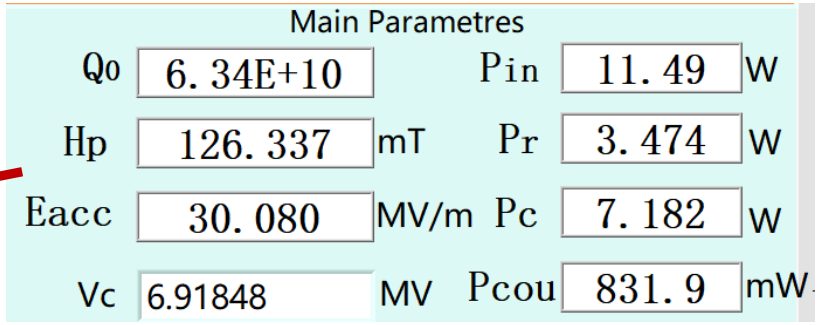


Exposure to air in cleanroom

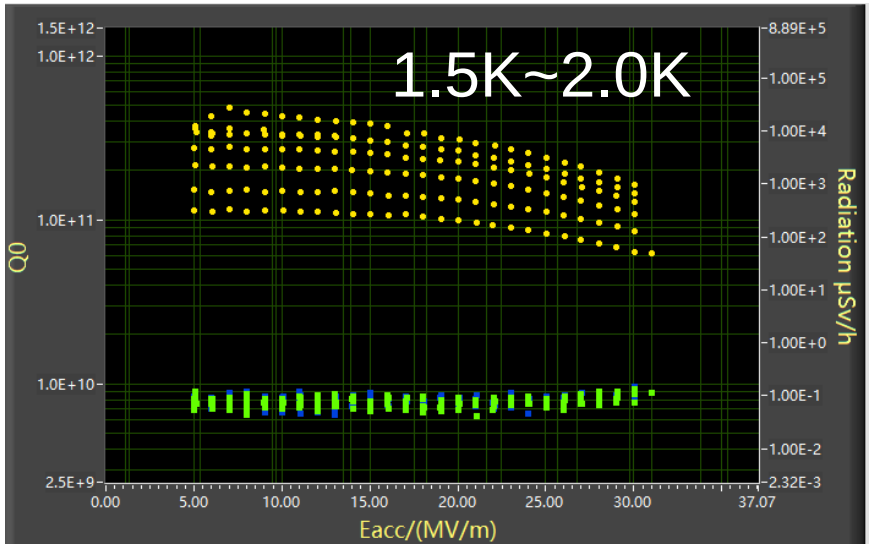
Mid-T furnace baking of 650 MHz 1-cell cavities (2)

- 650S5 demonstrated **fantastic** high *Q*. Mid-T furnace baking should be also effective to large elliptical cavity as well as 1.3 GHz. BTW: 650S4 is awaiting for test.
- Mid-T furnace baking seems more effective for 650 MHz than N-doping.



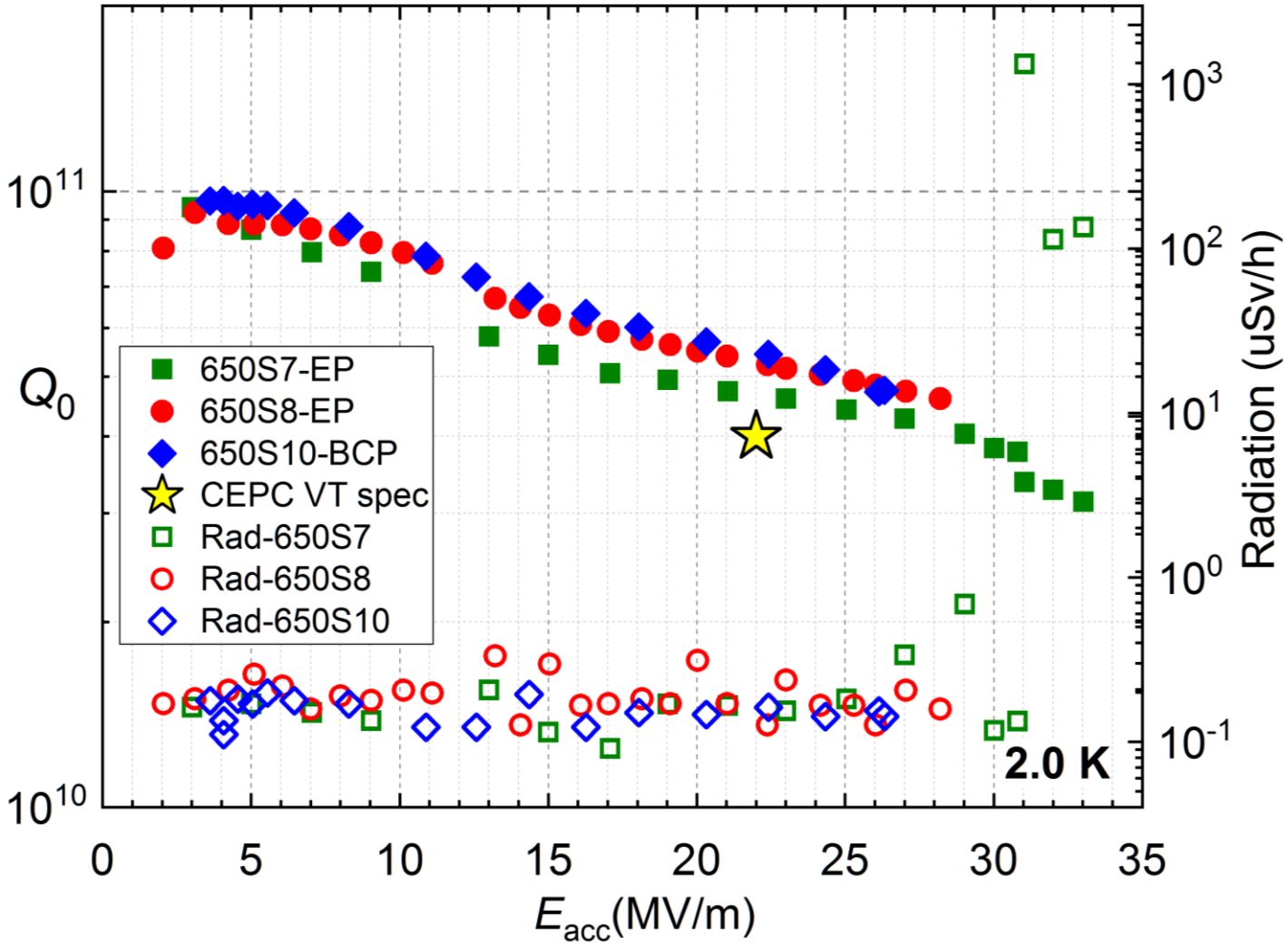


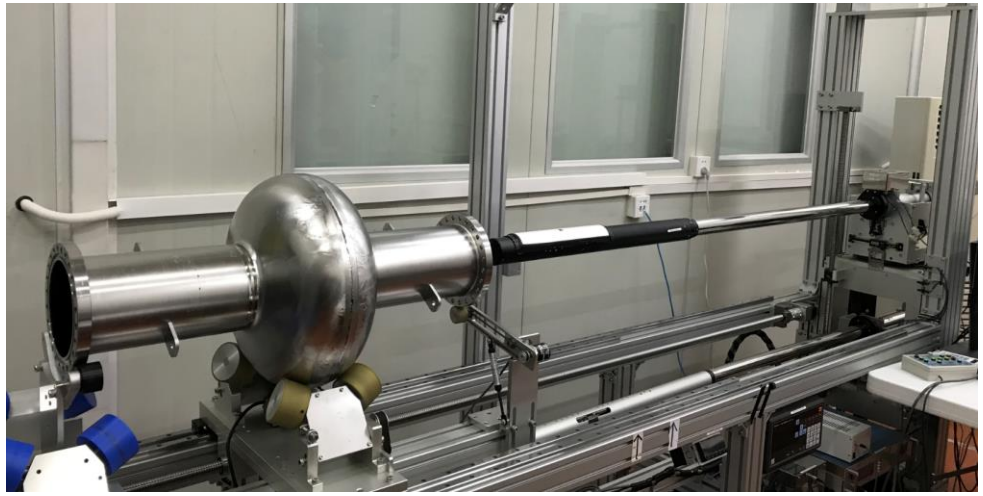
Significantly high Q & E_{acc}!



650 MHz 1-cell large-grain cavity

- Three large-grain cavities exceeded the CEPC spec.
- 650S10 (BCP processed) showed lower E_{acc} than 650S7 and 650S8, which were processed with EP.





Inspection

Cell (650S7)

Equator (650S7)

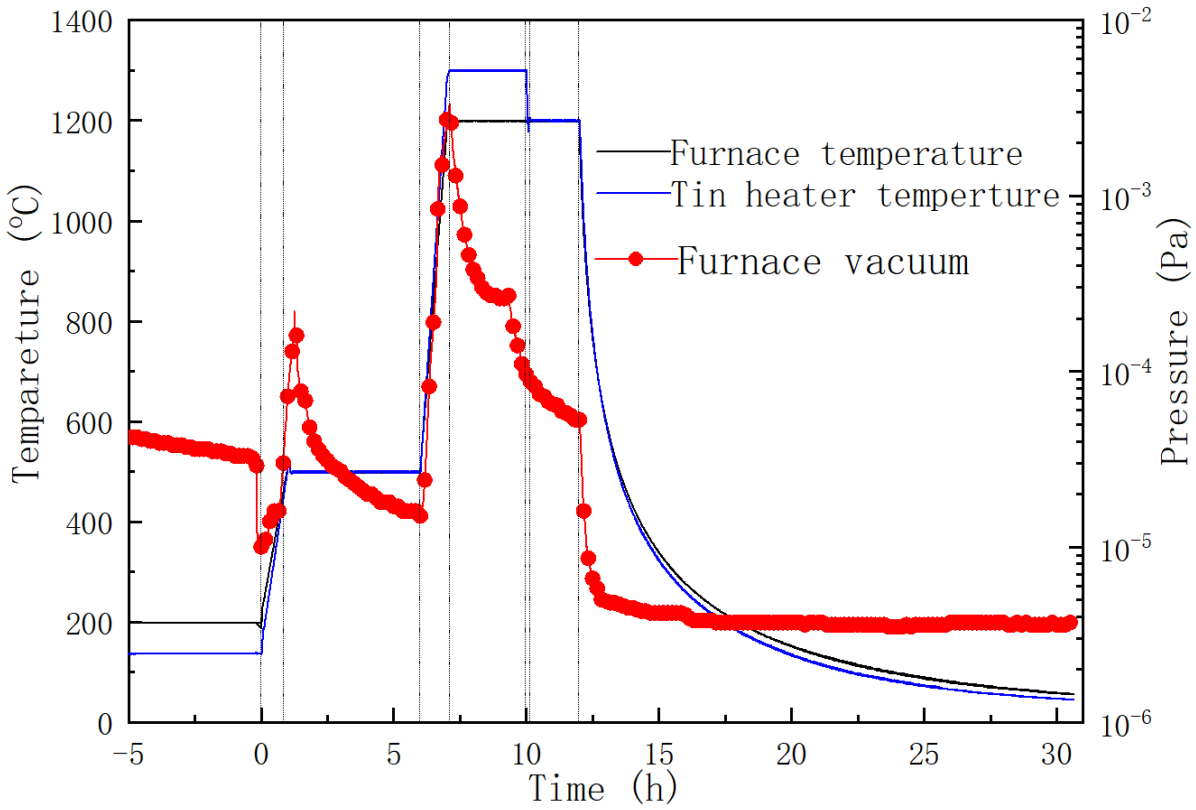
Outline

- 1.3 GHz 9-cell cavity
- 650 MHz 1-cell/2-cell cavity
- **Nb3Sn cavity**
- Conclusion

Setup

- A small furnace for Nb3Sn film coating was developed at IHEP. Nb3Sn film is coated with 1.3 GHz 1-cell niobium cavity by vapor diffusion.

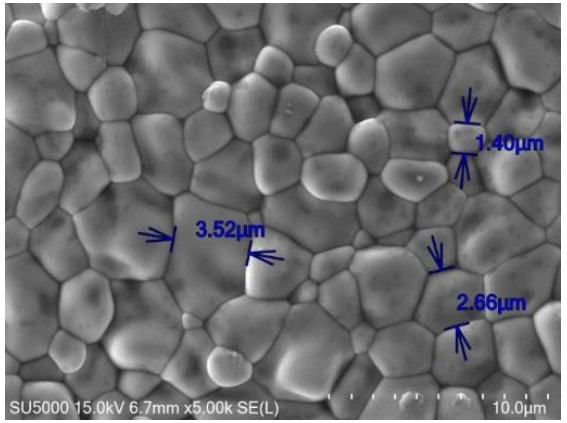
Furnace for Nb3Sn coating.

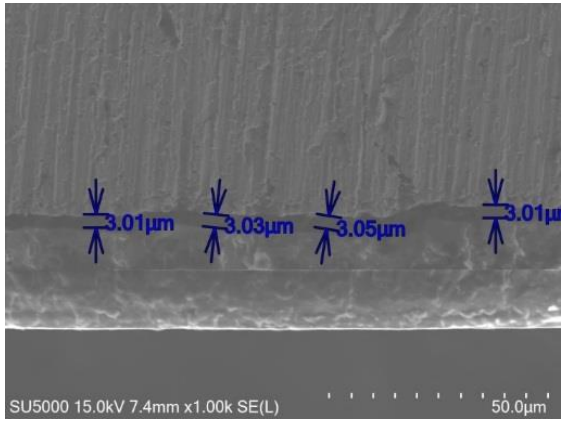


Curve of coating process

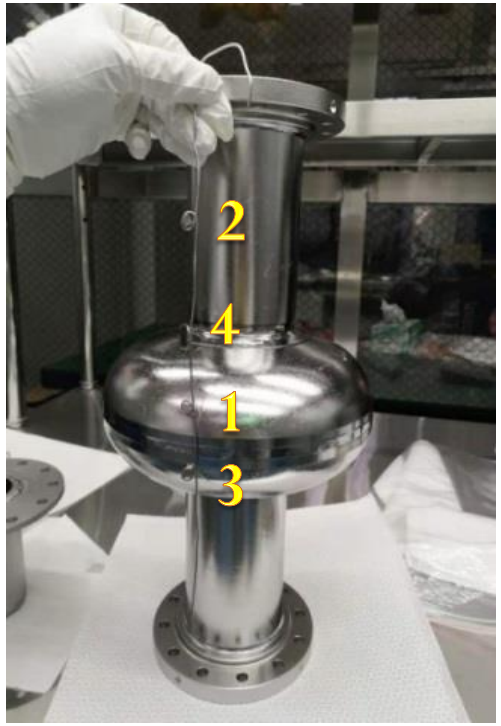
Microscopic analysis

- Samples were used for microscopic analysis, which showed formation and superconducting transition of Nb3Sn.

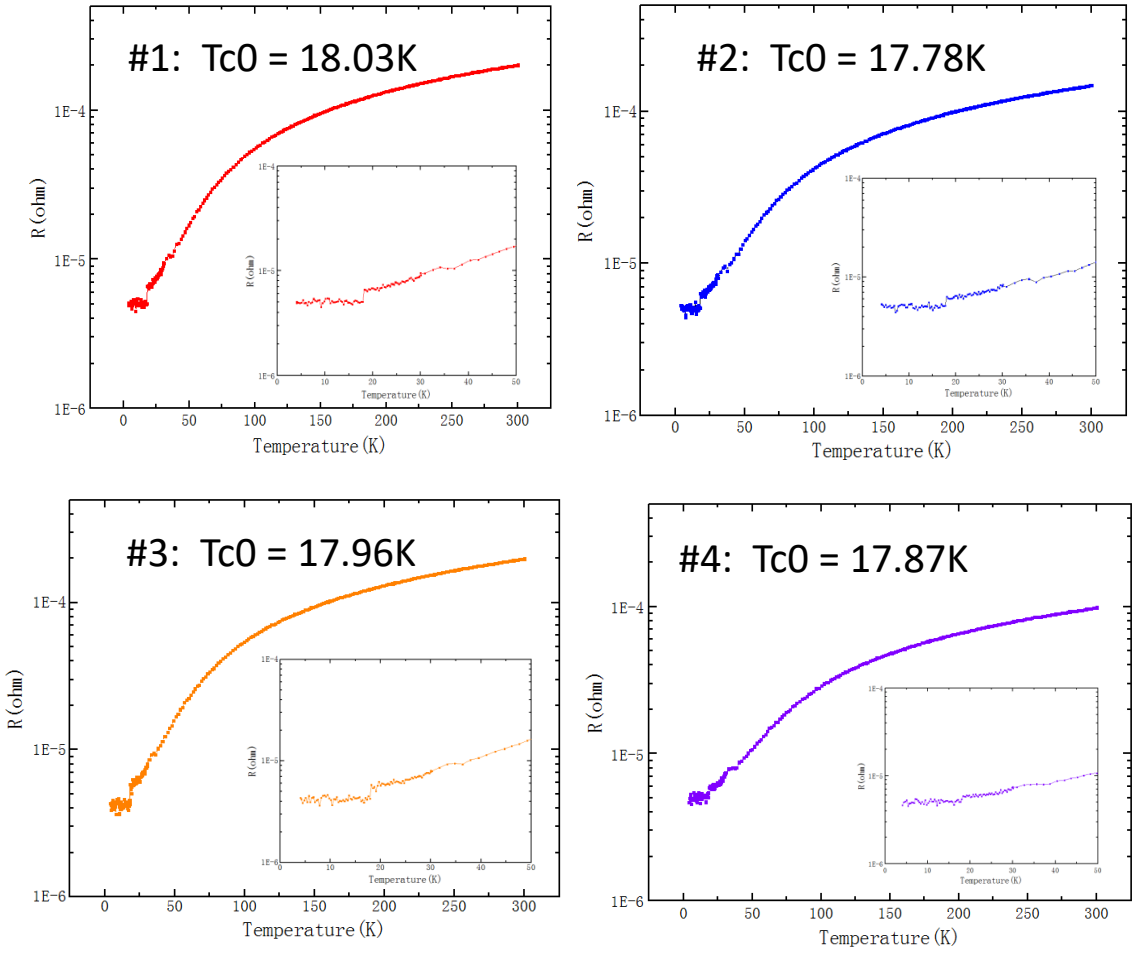




Nb3Sn grain (SEM)



Samples position

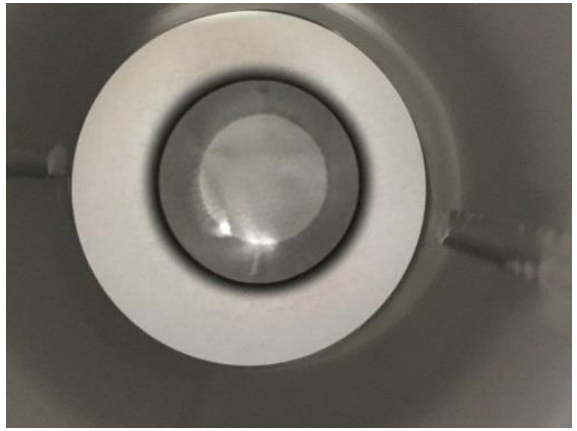


T_C of Nb3Sn (R-T)

Results of Nb3Sn coating (4.2 K)

- Max gradient: 5~7 MV/m; Max Q: ~3E9.
- The coating process still needs optimization.

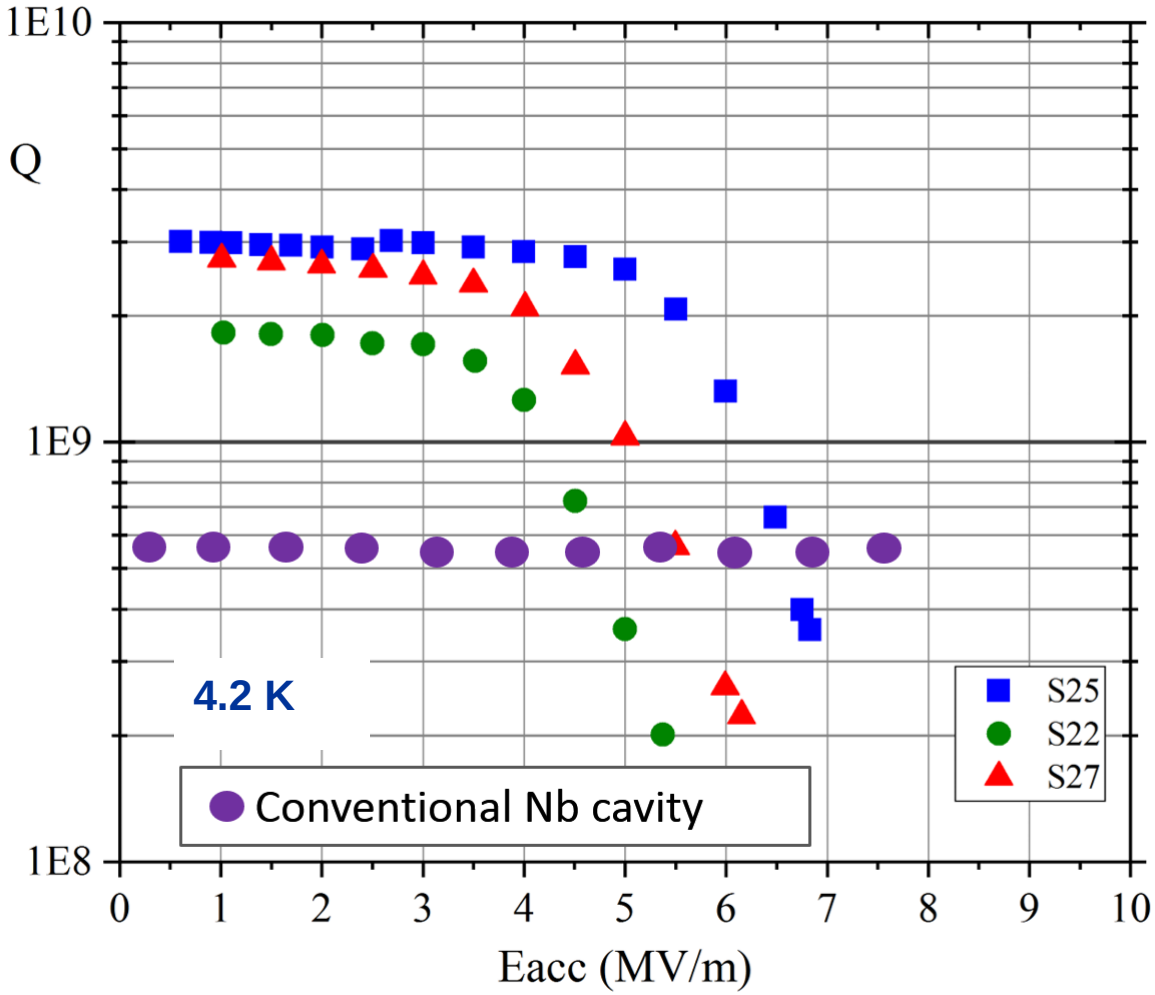
Cell before coating



Cell after coating

Equator before coating

Equator after coating

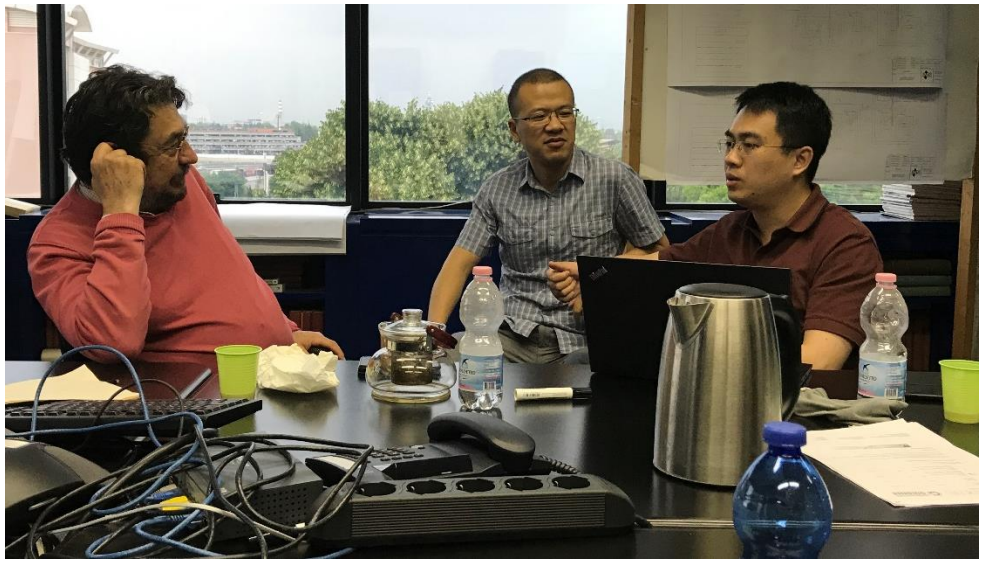


Vertical test results of Nb3Sn cavities

Conclusion

- State-of-the-art 650 MHz and 1.3 GHz superconducting cavities have been developed for CEPC. High Q and high E_{acc} have been both achieved successfully.
- New and novel technology are applied: mid-T furnace baking, large grain niobium, nitrogen doping/infusion, flexible polishing, electro-polishing, etc.
- Nb_3Sn coating has gained preliminary progress.
- CEPC SRF benefits a lot from the collaboration with KEK, INFN-LASA. Thanks to C. Pagni, E. Kako, K. Umemori and other colleagues.

KEK people's visit to PAPS (2018.9)



Visit to INFN-LASA (2017.6)

Thanks for your attention!

- Shanghai hard X-FEL（SHINE）：616 cavities（1.3GHz、3.9GHz）。
- China Initiative Accelerator Driven System（CIADS）：155 cavities（162.5MHz、325MHz、650MHz）。
- High Intensity heavy-ion Accelerator Facility（HIAF）：96 cavities（81.25MHz、162.5MHz、325MHz）。
- High Energy Photon Source（HEPS）：7 cavities（166.6MHz、500MHz）。