# New results of KEK N-infusion and mid-T bake

2020/Feb/4

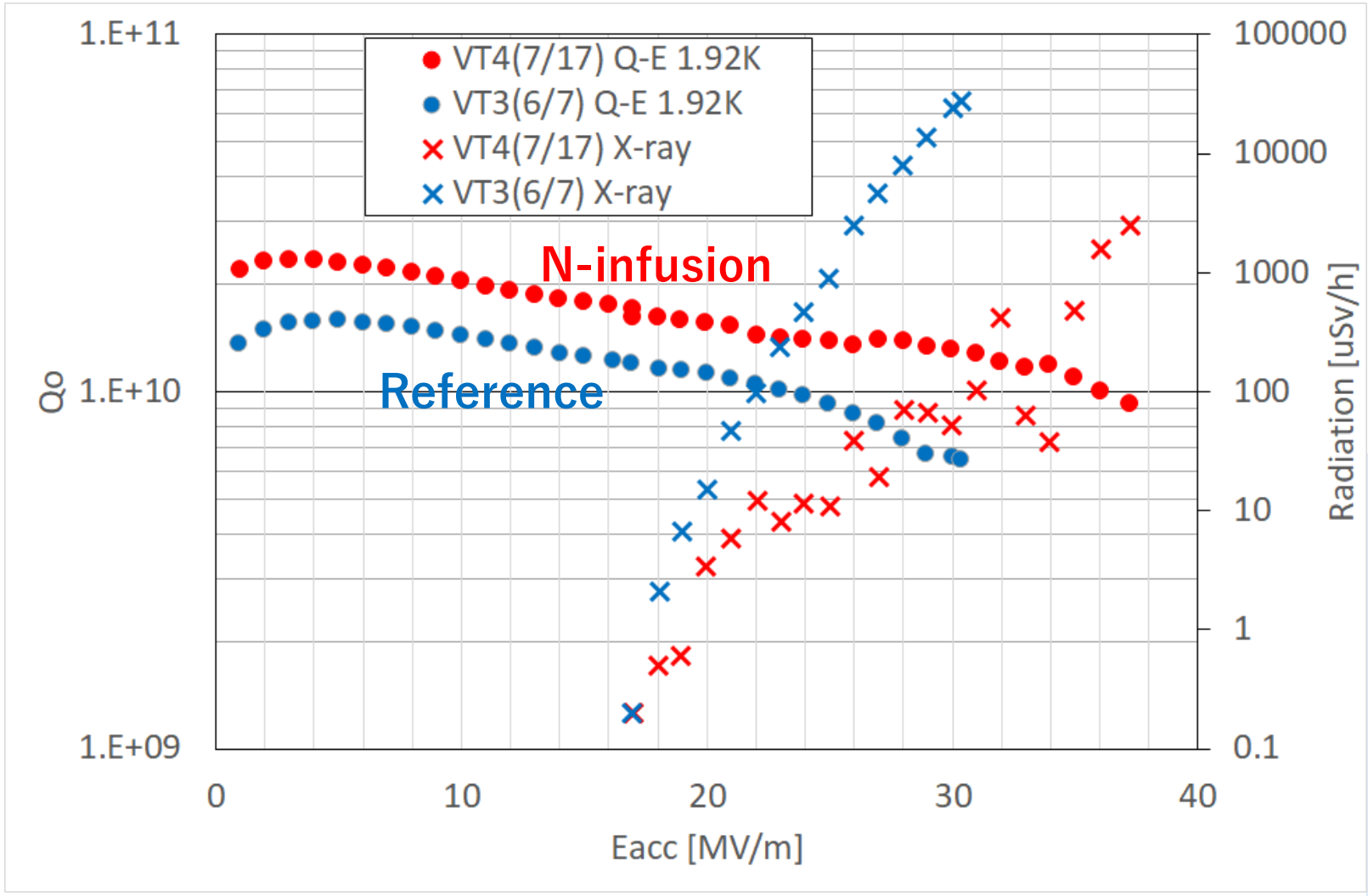
TTC meeting WG1 (@CERN)

KEK Kensei Umemori on behalf of KEK-SRF cavity group

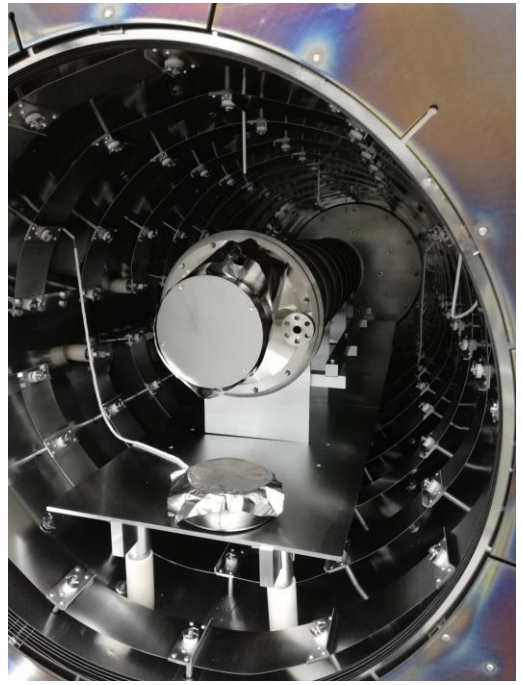
# Outline

- N-infusion results for 9-cell cavity
- High-Q results of mid-T baking for single cell cavities
- Discussion
- Summary

# First N-infusion for 9-cell cavity




※ Eacc for reference measurement was limited by F.E.



- Max Eacc = 37MV/m
- Quench：1-cell, 120deg.
- Final field emission onset Eacc = 20-21MV/m

- Successful N-infusion for 9-cell cavity.
- This cavity will be installed to STF-CM.

# Mid-T heat treatment in furnace

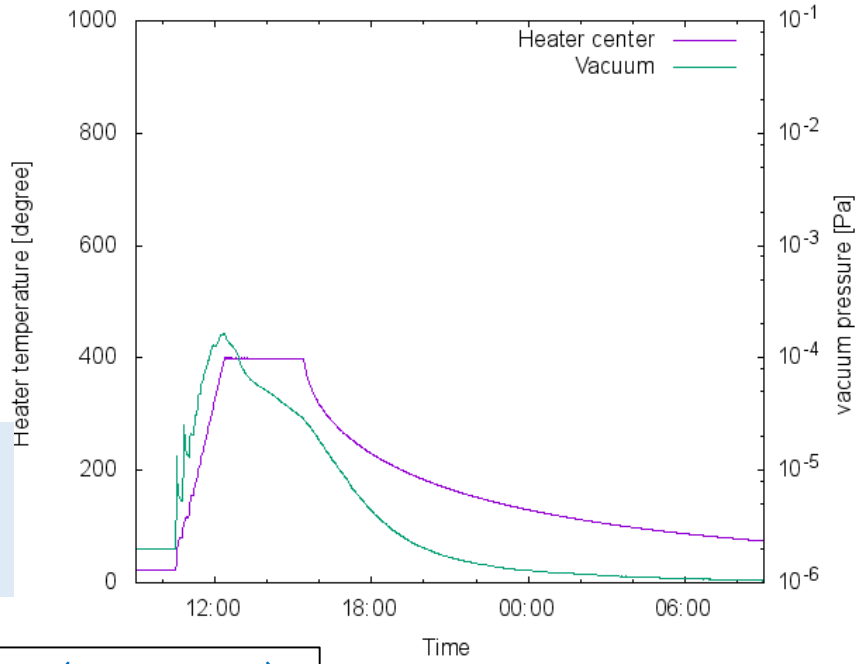
# History of cavities

## R-8 cavity (single cell)

- N-infusion at KEK furnace
- HPR, Assembly
- VT
- Disassembly

- HPR
- **Heat treatment (400C, 3h) at KEK furnace**
- HPR, Assembly(No baking)
- **VT**

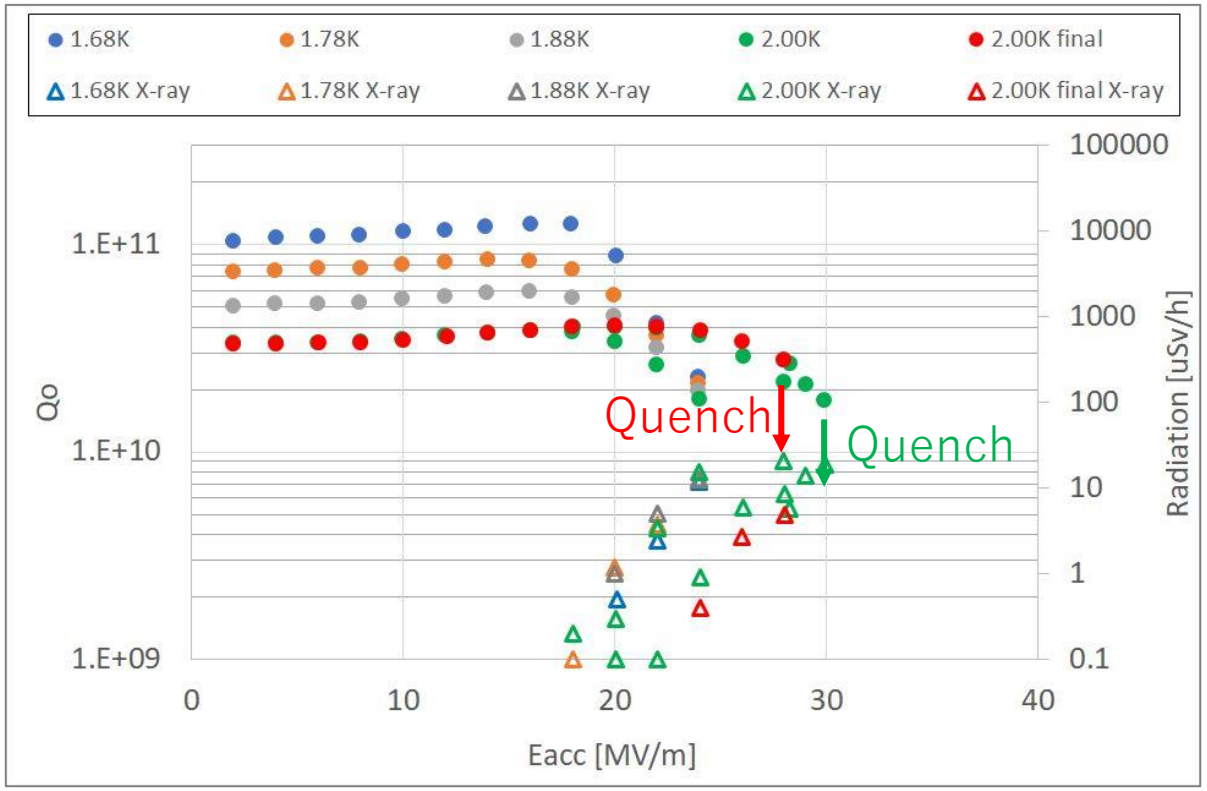
## AES-18 cavity (single cell)



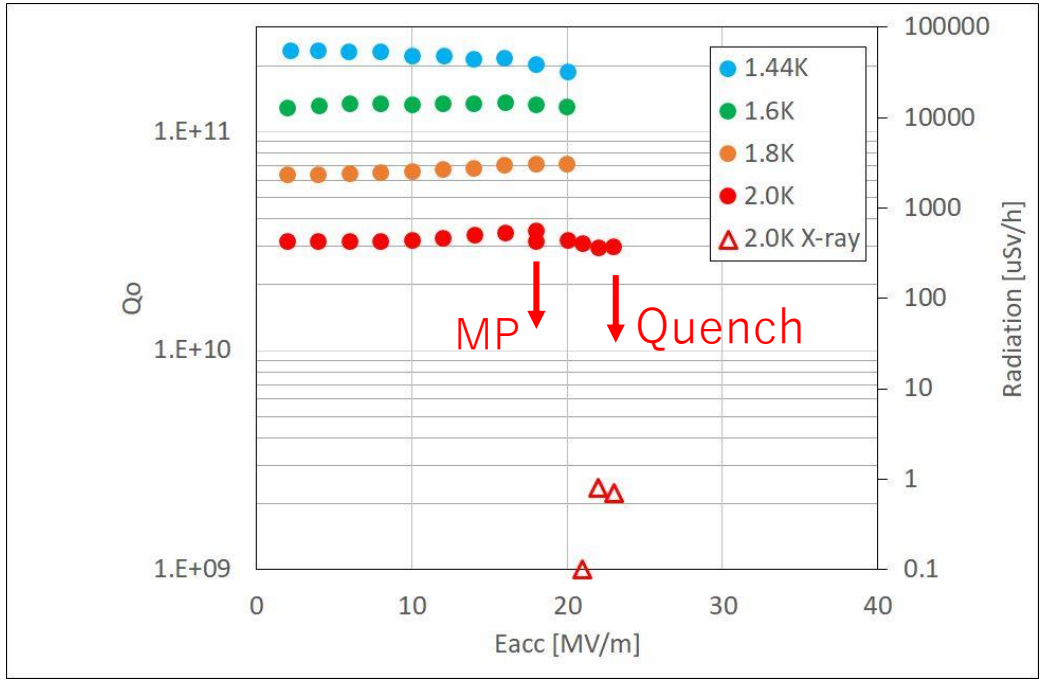

- Refresh EP(10um)

- HPR
- **Heat treatment (400C, 3h) at KEK furnace**
- HPR, Assembly(No baking)
- **VT**

## R-8 cavity

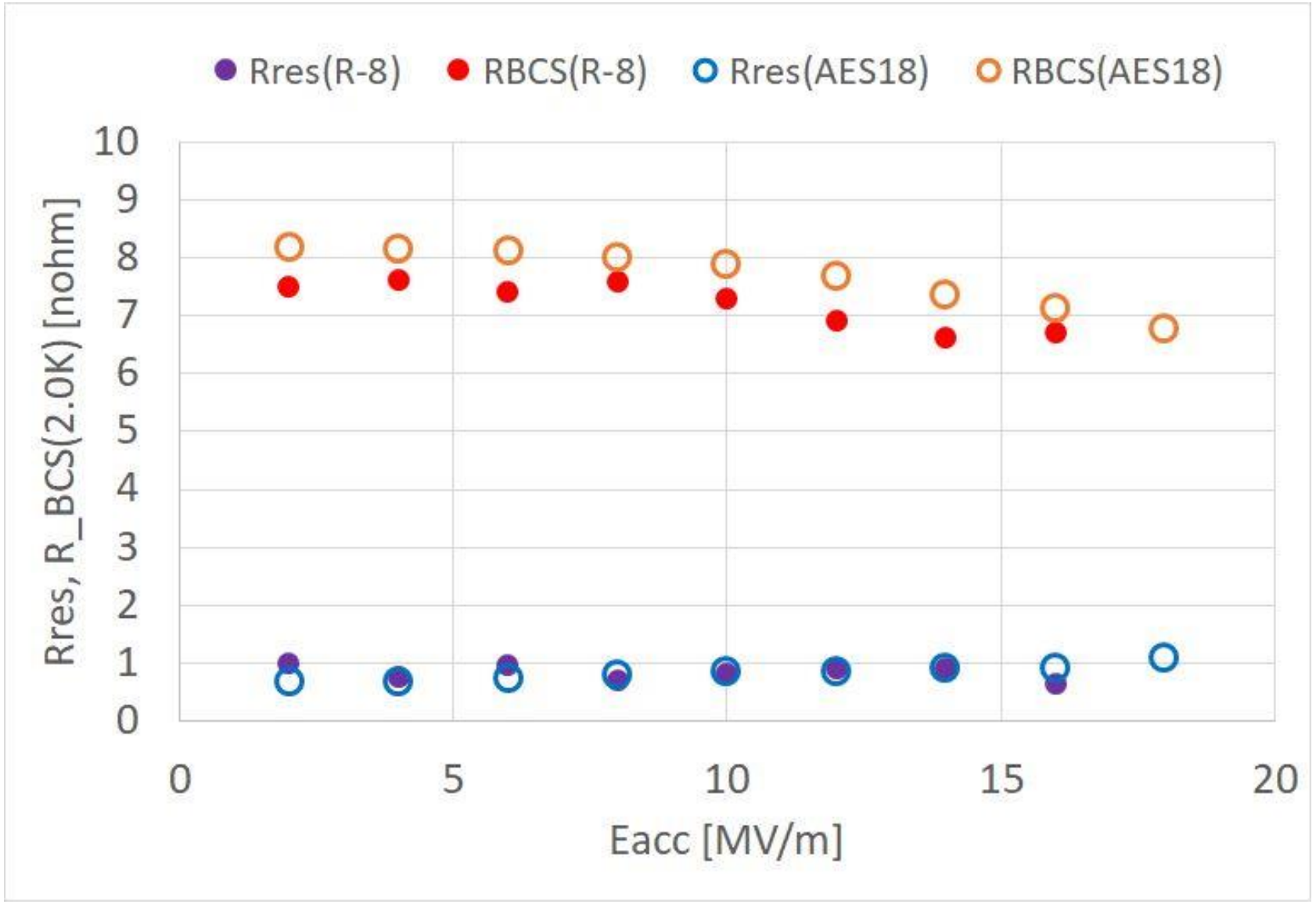



## AES18 cavity




- Both cavities show high-Q (> 3e10) and slight anti-Q slope.
- No HFQS(high field Q-slope) was observed up to 30 MV/m.
- Quench field was limited to 30 and 23 MV/m
  - R-8: Heating at equator ~175 deg.
  - AES18: Heating at equator ~300 deg.

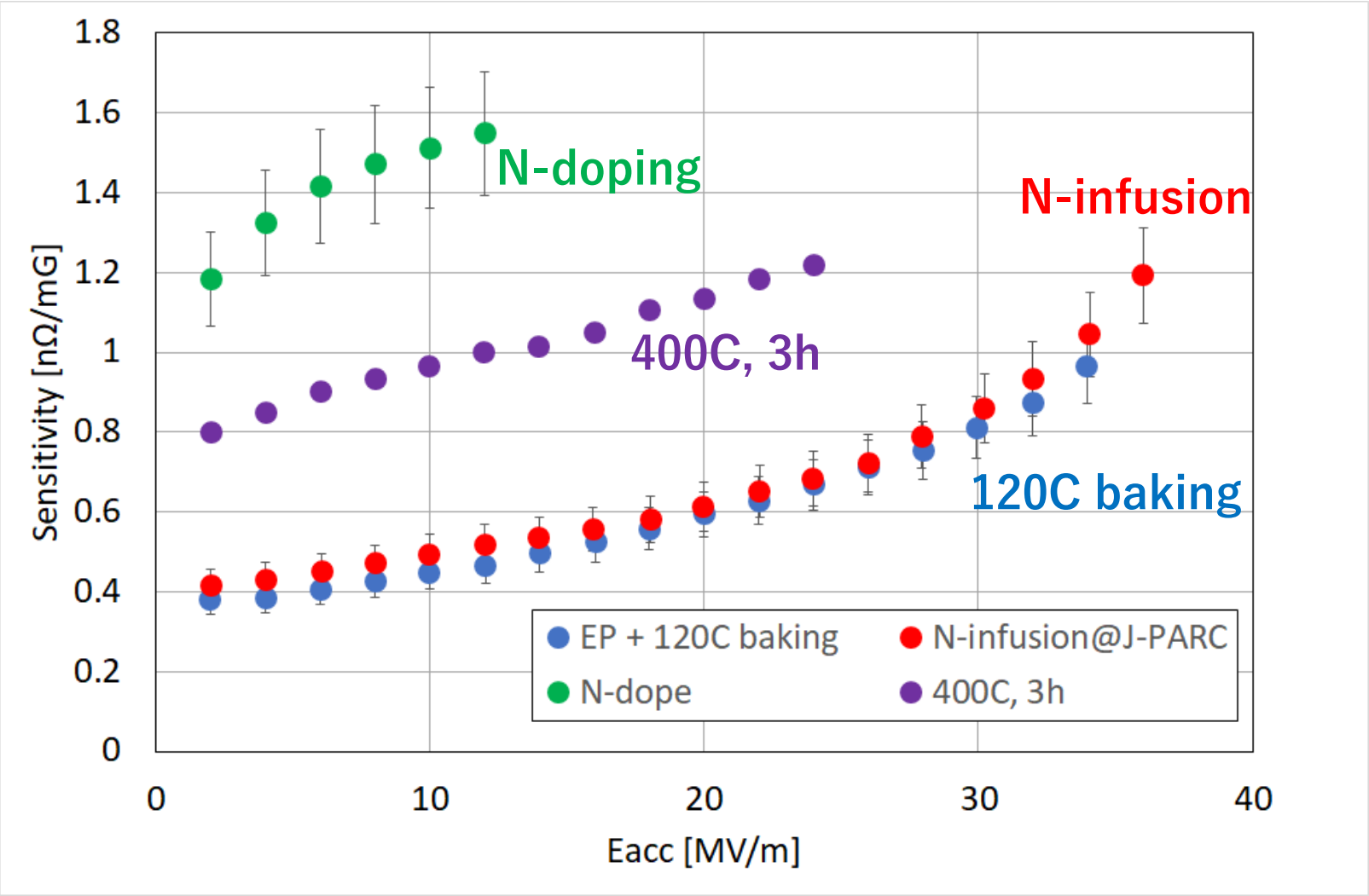
# Rres and Rbcs for R-8 and AES-18




- Slight decreasing of BCS resistance up to 18 MV/m
- Very small residual resistance, 1nΩ or less.

- Both cavities show similar behavior.

# Sensitivity [nΩ/mG] comparison



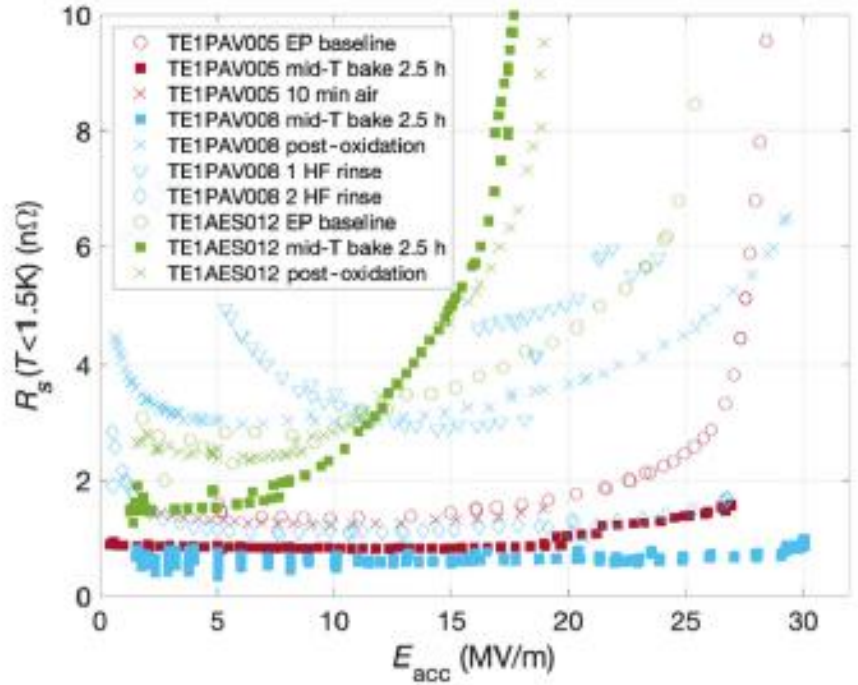

Sensitivity (trapped flux to residual resistance) for 400C, 3h is middle of N-infusion/EP+baking and N-doping.

# Why high-Q is achieved for 400C, 3h heat treatment, without $N_2$?

# FNAL mid-T results

PHYSICAL REVIEW APPLIED 13, 014024 (2020)

FNAL observed similar behavior for in-vacuum mid-T baking.




Mild anti-Q slope and very small residual resistance is observed.

**Ultralow Surface Resistance via Vacuum Heat Treatment of Superconducting Radio-Frequency Cavities**

S. Posen, * A. Romanenko, A. Grassellino, O.S. Melnychuk, and D.A. Sergatskov
*Fermi National Accelerator Laboratory, Batavia, Illinois, 60510, USA*

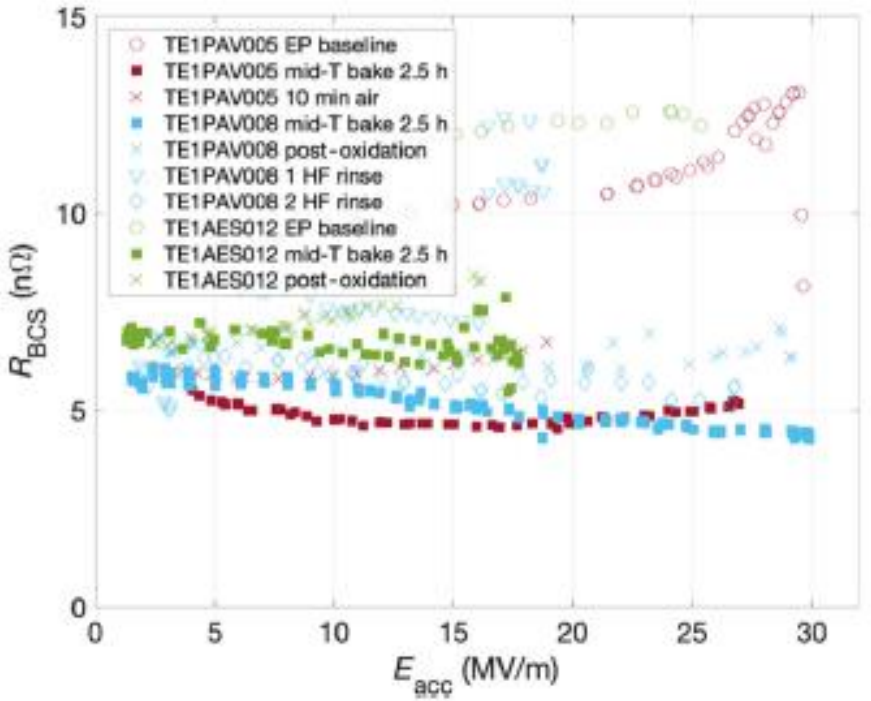



FIG. 6. Decomposed surface resistance of the three cavities from Fig. 5. Here $R_{BCS}$ (bottom) is calculated by subtracting the surface resistance at 1.4–1.5 K (top) from the surface resistance at 2.0 K.

# Sample analysis from DESY and collaborators

PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 103102 (2019)

Study on Nb surface analysis, while heating up inside vacuum chamber.

They show that surface distribution of Niobium oxide largely change above 250 C.

**Niobium near-surface composition during nitrogen infusion relevant for superconducting radio-frequency cavities**

G. D. L. Semione,[1,2,*] A. Dangwal Pandey,[1] S. Tober,[1,2] J. Pfrommer,[1] A. Poulain,[3] J. Drnec,[3] G. Schütz,[4] T. F. Keller,[1,2] H. Noei,[1] V. Vonk,[1] B. Foster,[1,2,5] and A. Stierle[1,2]

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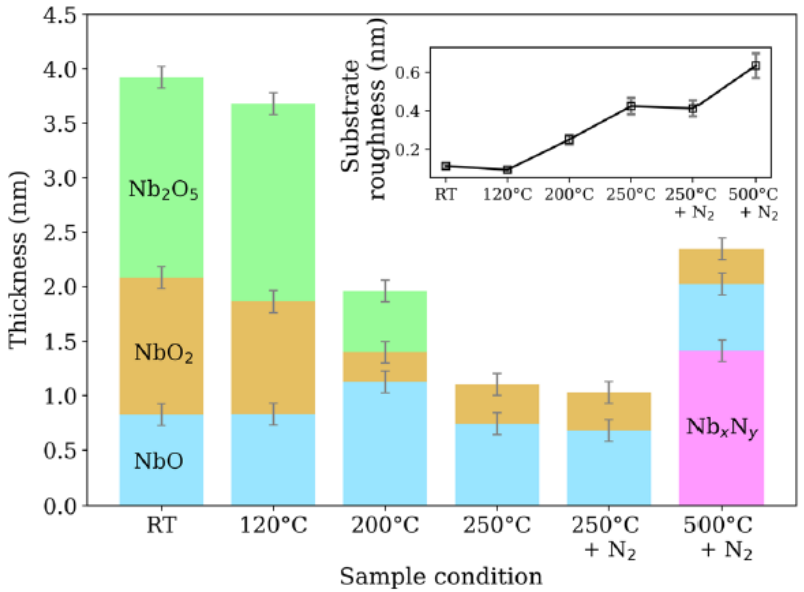



FIG. 4. Thickness and substrate roughness (inset) obtained by XRR in each step of the sample treatment.

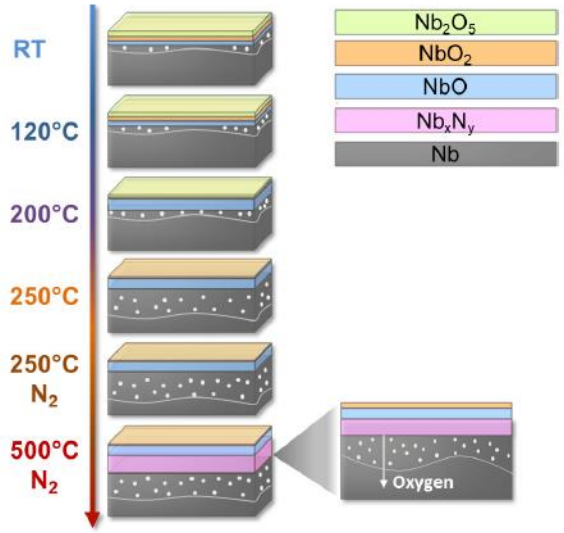



FIG. 9. Schematic representation of the stepwise annealing of Nb(100). The natural oxide layers gradually dissolve, and the liberated oxygen atoms diffuse into the Nb matrix. At 500 °C under a $N_2$ atmosphere, a $Nb_xN_y$ layer is formed underneath the remaining niobium oxides.

# Discussion

- It is clear that high-Q performance was observed without $N_2$ treatment.
- No HFQS was observed for 400C, 3h. (800C, 3h heat treatment show HFQS.)
- Oxide layer seems to play important role to improve cavity performance.
- What is the mechanism to improve Q-value?
- What is reason of lower field quench?
- Why 400C heat treatment works well?
- How is 200C, 300C, 500C, 600C heat treatment??
- What's happen, if we apply N-doping or N-infusion for 400C, 3h HT surface??

# Summary

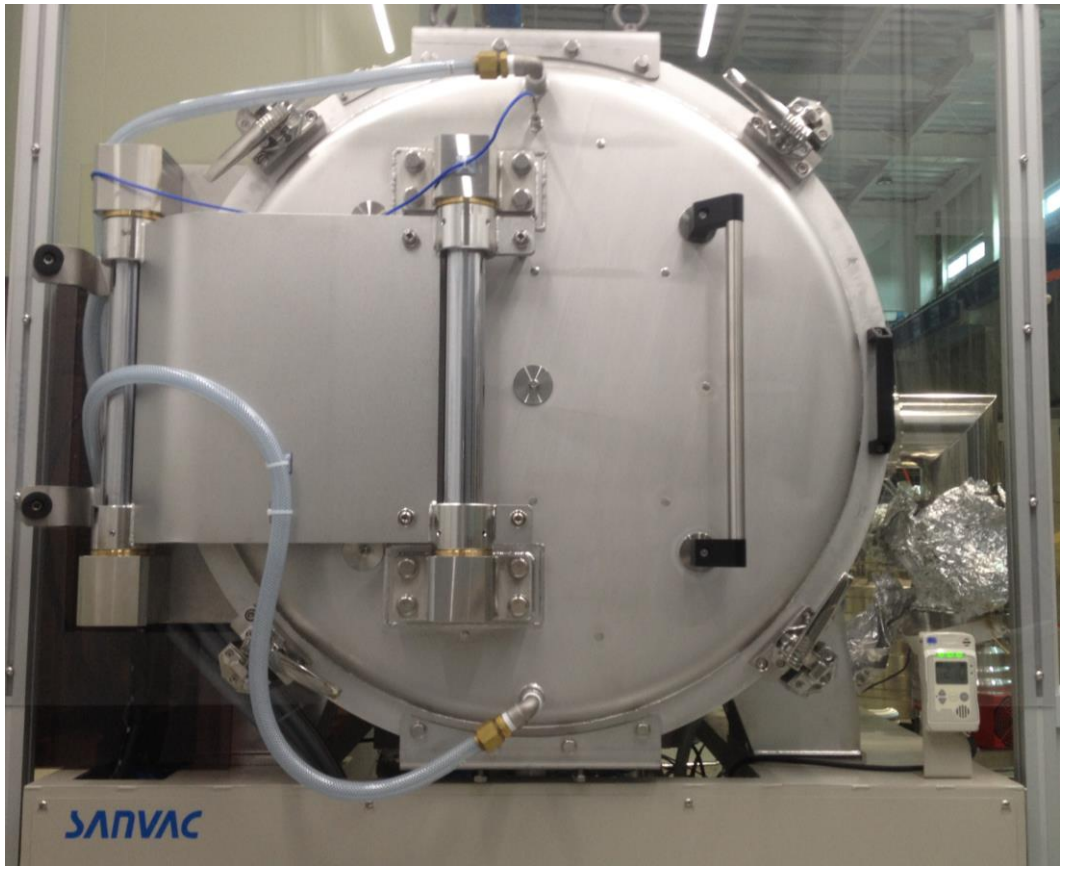
- N-infusion was applied to STF(TESLA-like) 9-cell cavity. It was successful and Eacc reached to 37 MV/m without Q-degradation.

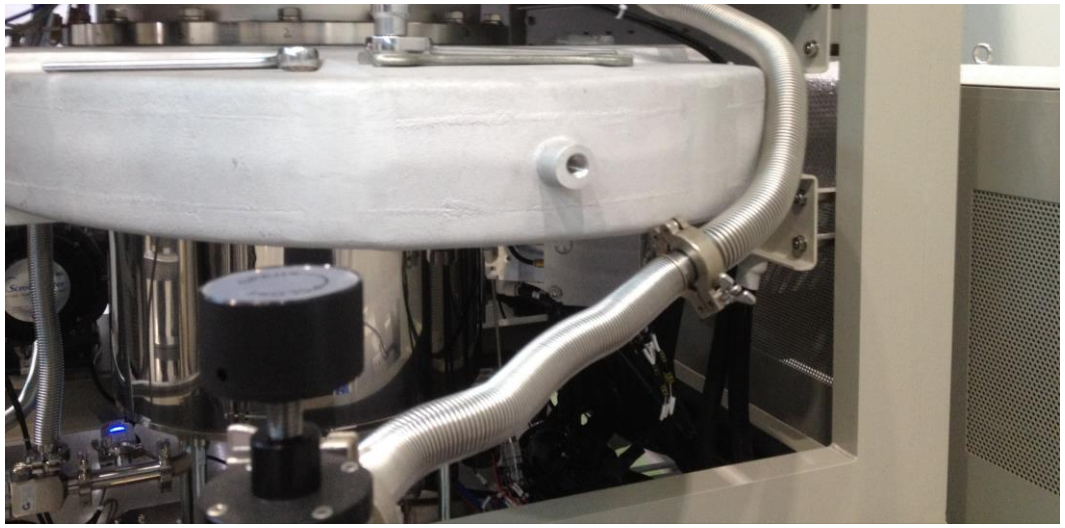
- 400C, 3h heat treatment was applied to single cell cavities.
- Two cavities showed high-Q performance with slight anti Q-slope.

- Around 300~500C is very interesting temperature. We will continue R&D works.

# Backup slide

# KEK furnace(located at COI)



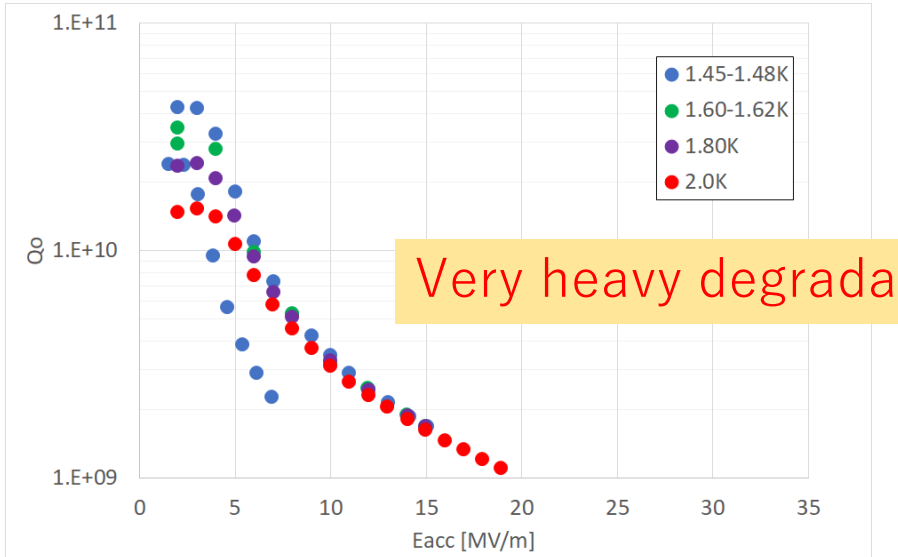



- Completed at the end of FY2017
- Cryopump for main pump, oil-free pumping system.
- Molybdenum is used for heater, reflector, table etc.
- TMP is used during N-injection, can reach ~2e-5Pa.
- Clean-booth surround entrance door.

| # | Day (N-inf / VT) | Cavity name | # of cell | Nb | Treatment | Results | Eacc (MV/m) | Comment |
|---|---|---|---|---|---|---|---|---|
| 1 | 2018/Jun | R-6 | 1 | FG | 800C, 3h + 120C, 48h, 3.3Pa N2 | No Q-degradation | 35 | |
| 2 | 2018/Jun, Jul | R-9b | 1 | FG | 800C, 3h + 120C, 48h, 3.3Pa N2 | No Q-degradation | 26 | Defect limited |
| 3 | 2018/Jun, Jul | R-10 | 3 | LG | 800C, 3h + 120C, 48h, 3.3Pa N2 | No Q-degradation | 27 | F.E. limited |
| Summer shutdown | | | | | | | | |
| 4 | 2018/Sep, Oct | R-2 | 1 | FG | 800C, 3h + 160C, 48h, 3.3Pa N2 | Q-degradation | 19 | No defects found |
| 5 | 2018/Oct | R-6 | 1 | FG | 800C, 3h + 120C, 48h (without N2) | Q-degradation | 32 | |
| Apply dedicated burning run after this period | | | | | | | | |
| 6 | 2018/Nov, Dec | R-8 | 1 | FG | 800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2 | Better Q than reference | 36 | |
| Improve cooling of cryo-pump by adding cooling-water type shielding plate | | | | | | | | |
| 7 | 2018/Dec 2019/Jan | R-9b | 1 | FG | 800C, 3h + 800C, 2h + 160C, 48h, 3.3Pa N2 | Q-degradation | 24 | Defect limited |
| 8 | 2019/Jan, Feb | AES18 | 1 | FG | 800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2 | No Q-degradation | 38 | |
| Modify N2 injection line | | | | | | | | |
| 9 | 2019/Apr | R-4 | 1 | FG | 800C, 3h + 120C, 48h, 3.3Pa N2 | Q-degradation | 39 | |
| 10 | 2019/May | AES18 | 1 | FG | 800C, 3h + 120C, 48h, 3.3Pa N2 | Q-degradation | 31 | |
| Remove cooling-water type shielding plate due to water leak trouble | | | | | | | | |
| 11 | 2019/Jun, Jul | MHI31 | 9 | FG | 800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2 | Better Q than reference | 37 | |
| 12 | 2019/Sep | R-4 | 1 | FG | 800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2 | Q-degradation | 36 | |

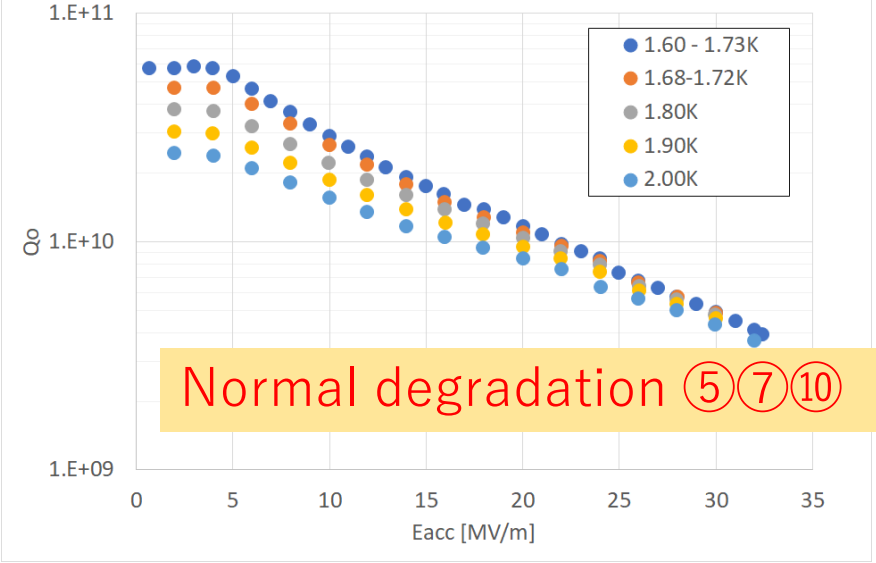
# Example of Q-degradation

## ④ 4th N-infusion (160C) at COI, R-2



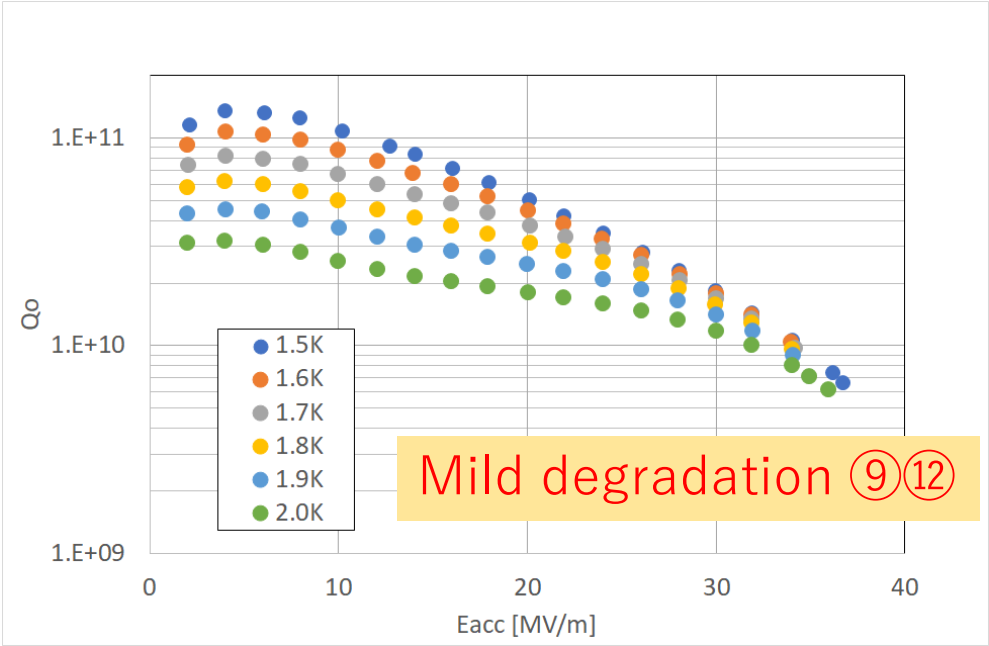

Very heavy degradation ④

## ⑤ 5th N-infusion(120C, w/o N2) at COI, R-6




Normal degradation ⑤⑦⑩

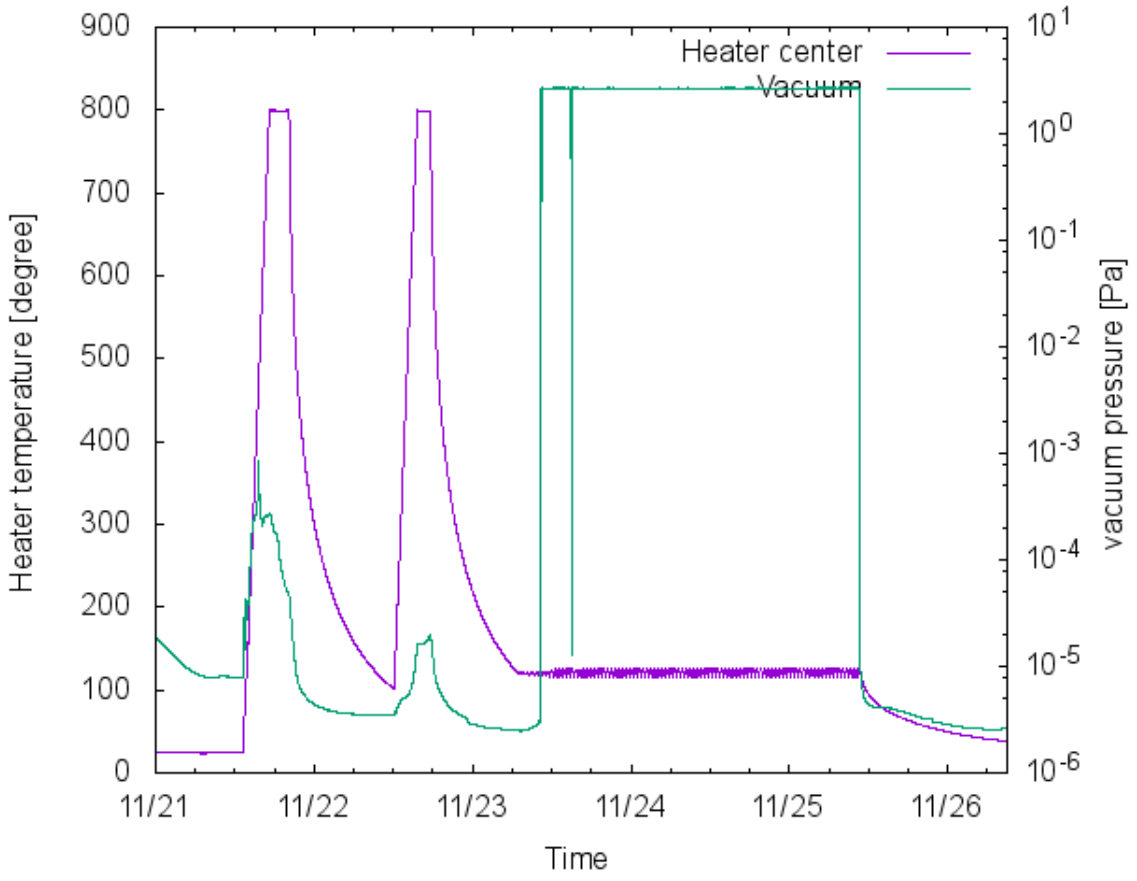
## ⑫ 12th N-infusion (120C) at COI, R-4




Mild degradation ⑨⑫

- Q-degradation occurred even at KEK New furnace.
- What's reason of degradation??
- Lack of burning run after summer?

# Process, “800C, 3h + 800C, 2h + 120C, 48h, N2”




- **“Better vacuum” or “less hydrogen” might be necessary condition for N-infusion.**
- **Is Hydrogen key components?**

- 1st 800C heat treatment
  - ➢De-gassing of cavity
  - ➢One important target is Hydrogen
- 2nd 800C heat treatment
  - ➢Much better vacuum condition
  - ➢Less absorption on cavity surface
  - ➢“H” start to rise after 2 hours, due to temperature rise of cryo-pump.
- 120C, N-infusion
  - ➢Normal N-injection procedure
  - ➢3.3Pa N2 injection for 48 hours.