# Recent RF test results of Nb/Cu full-seamless 1.3 GHz cavities

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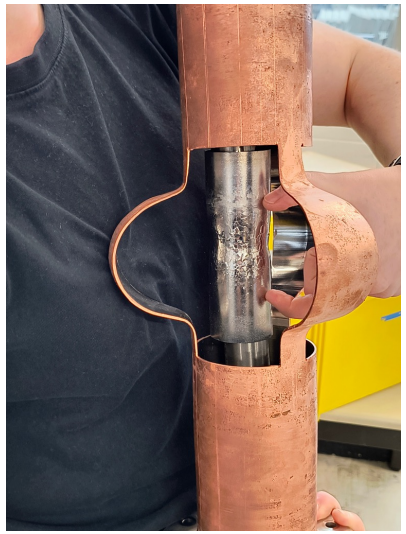
# KEK/CERN Collaboration for Nb/Cu R&D

## CERN

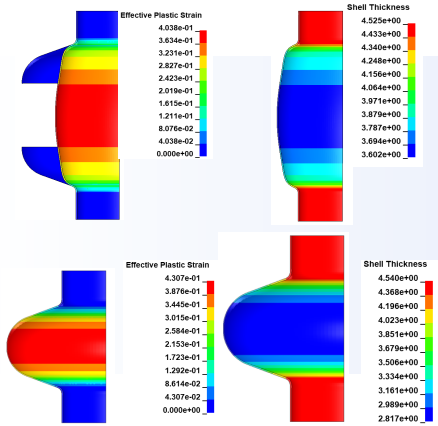
- Nb/Cu cavity development from LEP
- HiPIMS coating facility
- Copper tube hydroforming
- FCC

## KEK

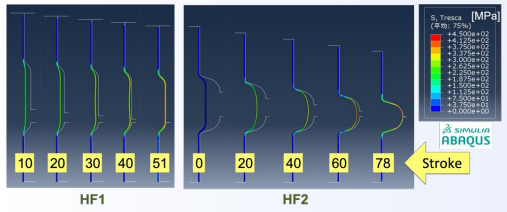
- Bulk Nb cavity development from TRISTAN
- 1.3 GHz processing facility
- Bulk Nb hydroforming
- ILC



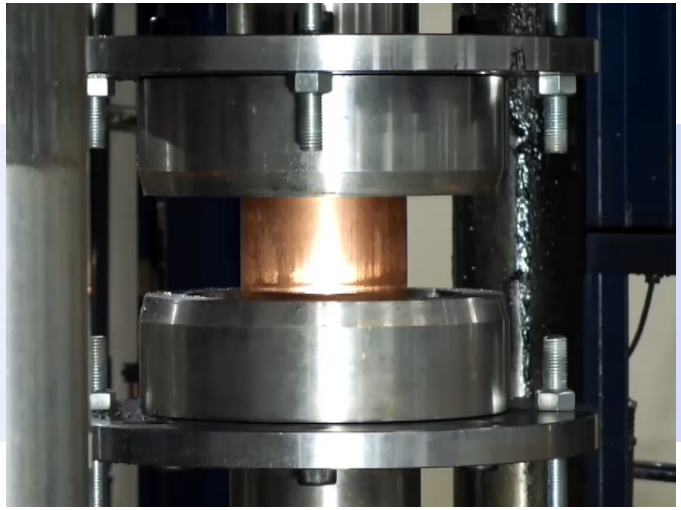
# 1.3 GHz cavity fabrication



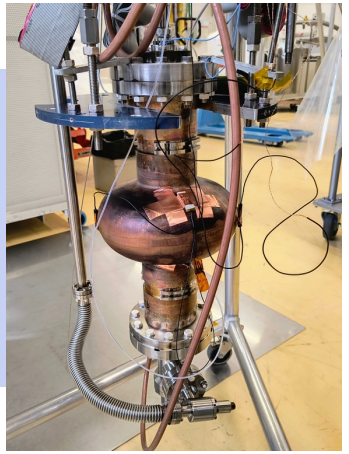

Simulation



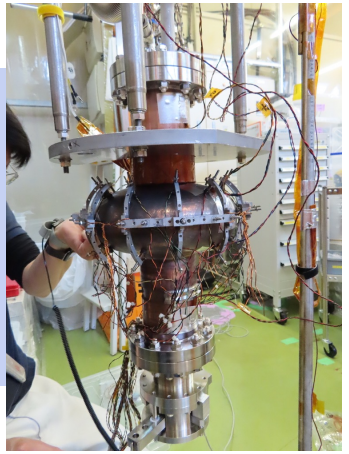

Hydroforming



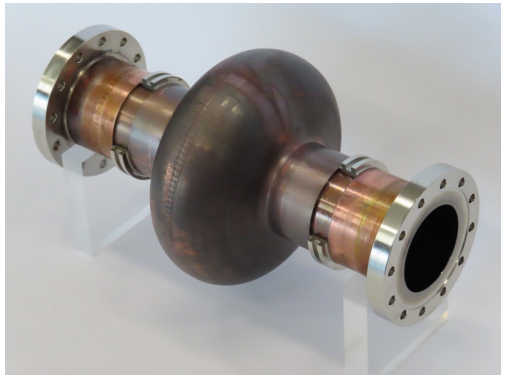
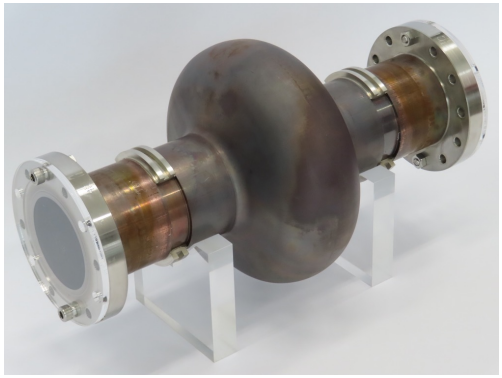
Coating



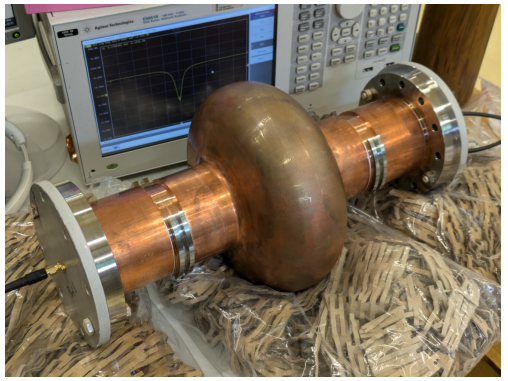
Measurement



# Cavities overview

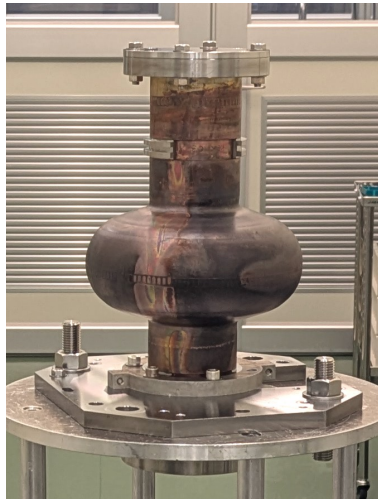
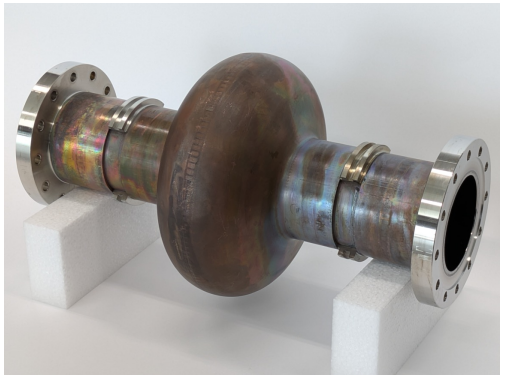
**C1, C1b**
The first series of full-seamless

**C1c, C1d**
Hydroforming + Plasma EP


**KEK14, KEK15**
Brazed and welded
with CF flanges

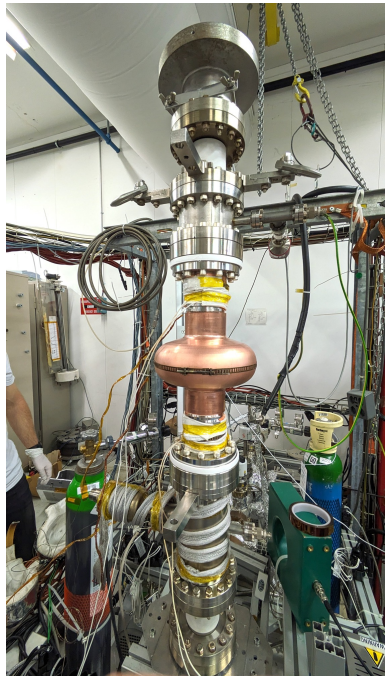
**C3, C3b**
Mechanical polishing
+ Hydroforming

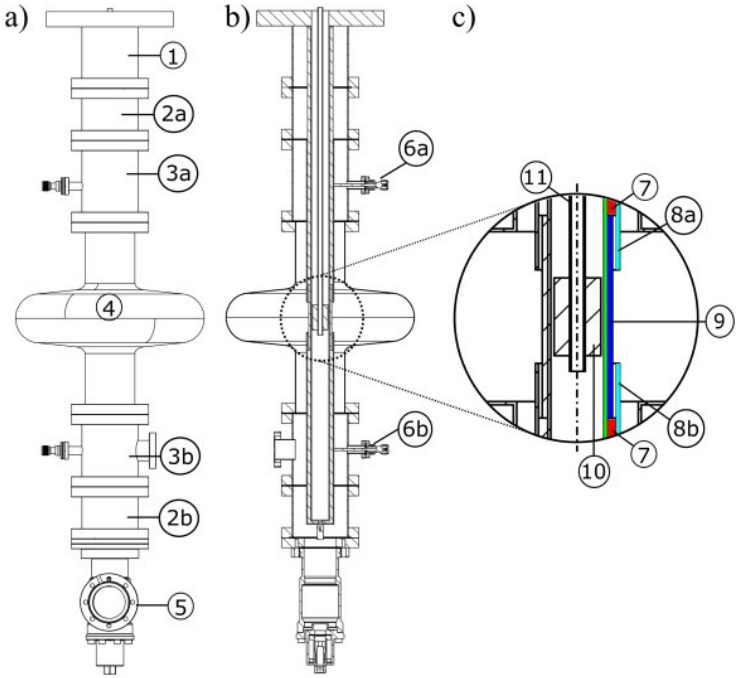



# Nb thin film coating

## Process parameters

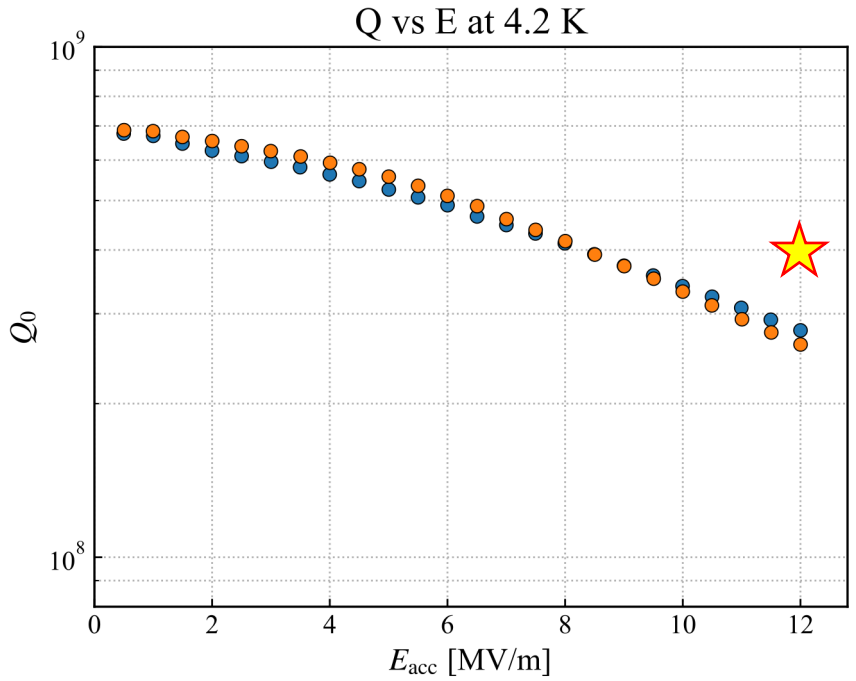
- EP: 40 minutes, target 12 um removed material.
- HPR: 100 bars, 3 hours, cavity dried under vacuum at 50˚C
- Bakeout: 48h, 200˚C, base pressure ~ $2\times10^{-10}$ mbar
- Coating: **HiPIMS**
  - Cut-offs: 350W, $2.5\times10^{-2}$ mbar Kr, 6 positions/cut-off, 150˚C, unbiased
  - Cell: 2 kW, $2.5\times10^{-3}$ mbar Kr, 6 hours, 150˚C, -75V bias voltage
  - Targeted thickness at the equator: **6 um**

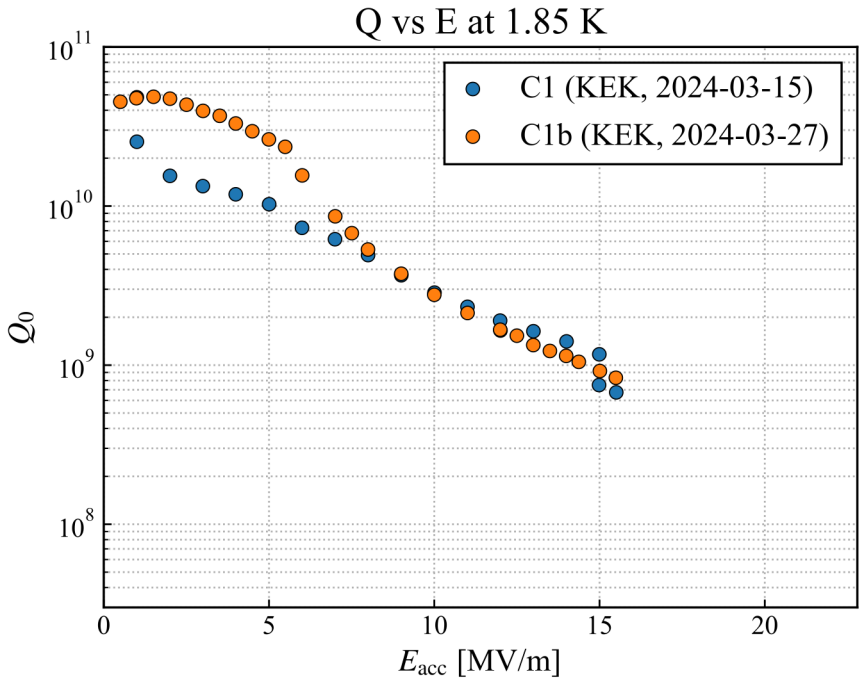





https://doi.org/10.1016/j.surfcoat.2022.128306

# The first series

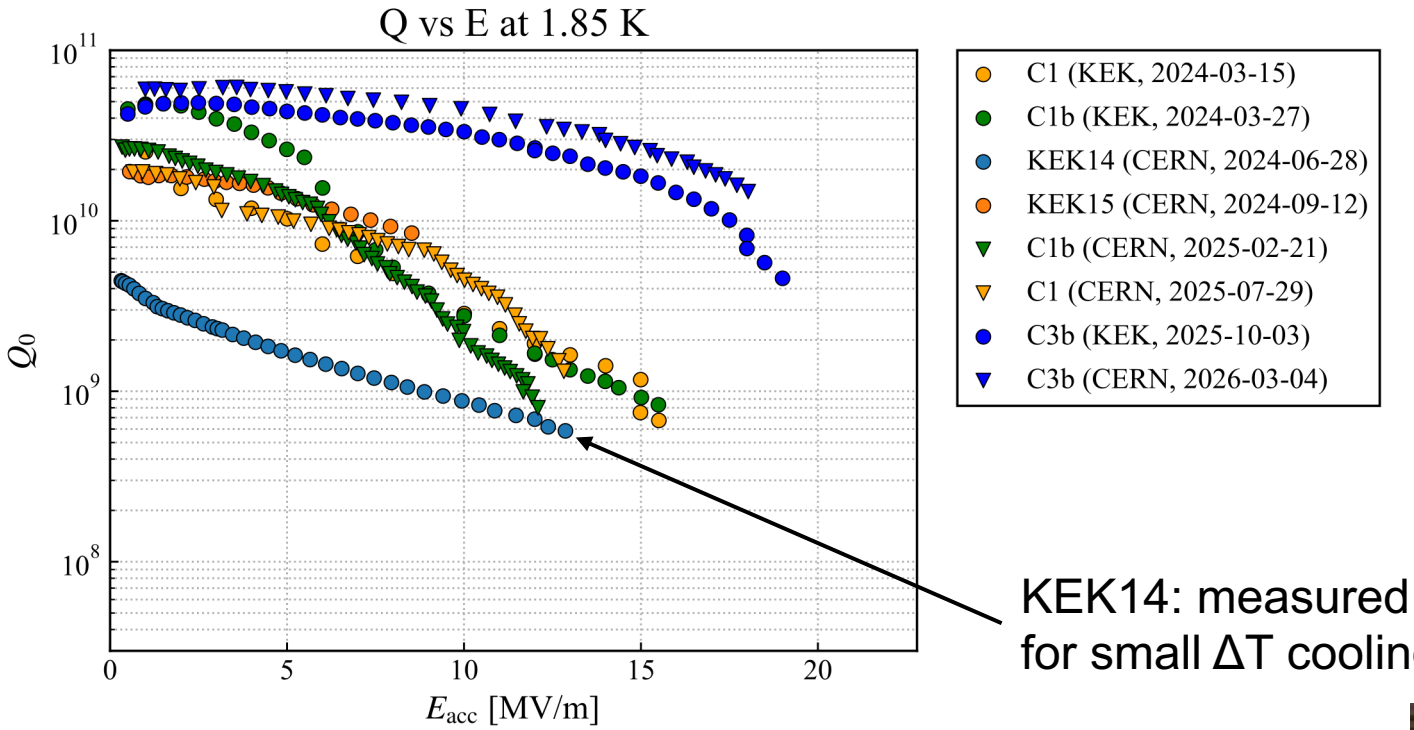



## C1 and C1b (2024-03)

- Our target: $Q_0 > 4\times10^8$ at 12 MV/m, 4.2 K
  - Acc. gradient: Cleared
  - Quality factor: Just short of the target
- 1.85 K
  - High-Q in low field and Q-drop
  - Max $E_{acc}$: 15.5 MV/m

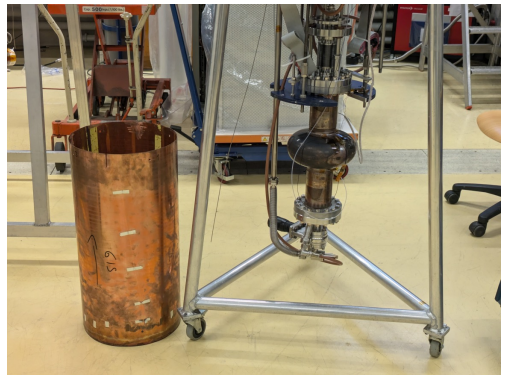
# Measurements at CERN



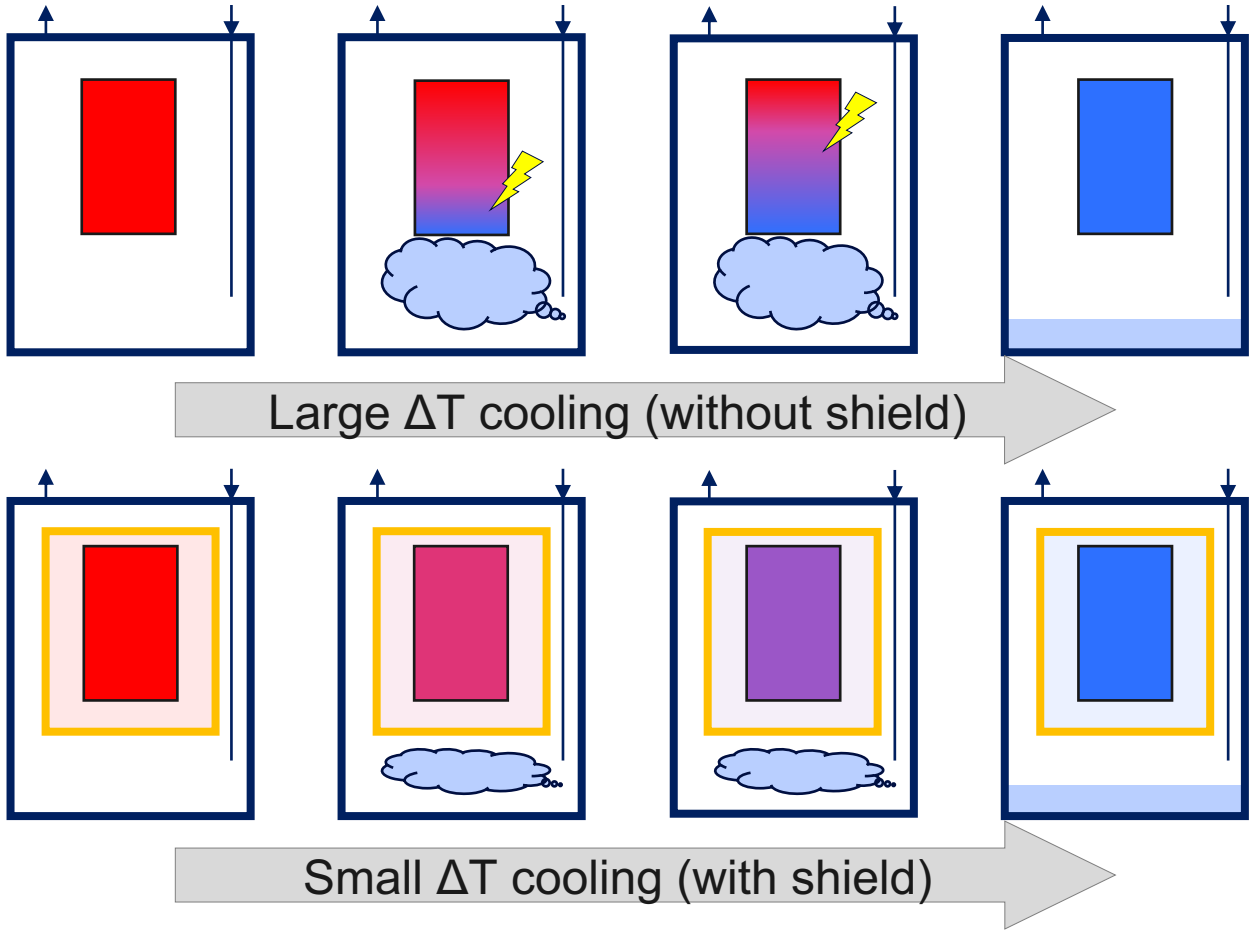

KEK14: measured w/o the shield for small ΔT cooling

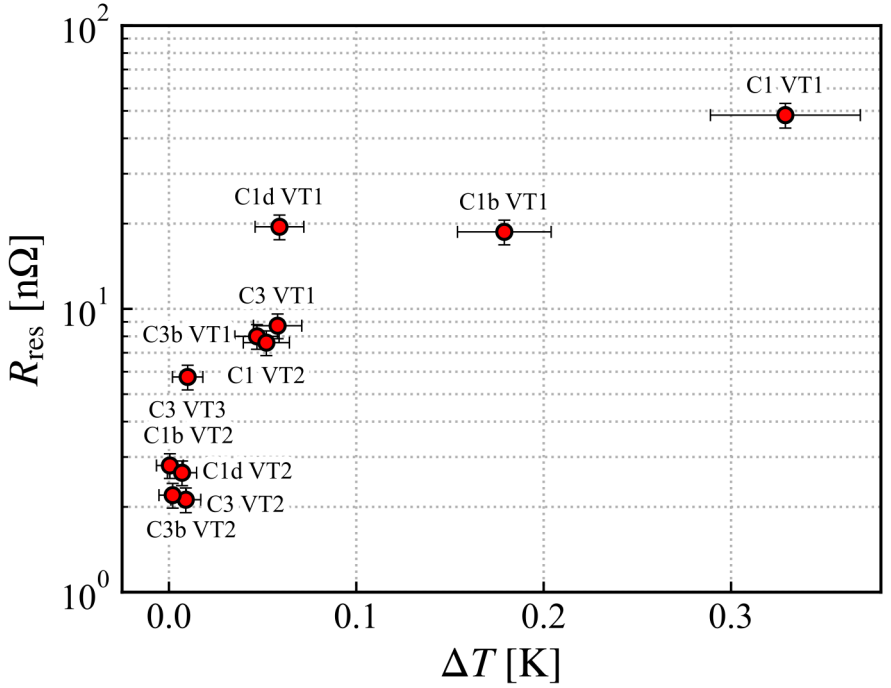
## KEK14, KEK15, C1 and C1b (2024-06 to 2025-07)

- Consistent results came out from the same cavity measured in both KEK and CERN
- Improved cool-down method
  - Spatial temperature difference $\Delta T$ at $T_c$ affects surface resistance.
  - Covering the cavity with a cylindrical shield worked well.



# Thermoelectric current

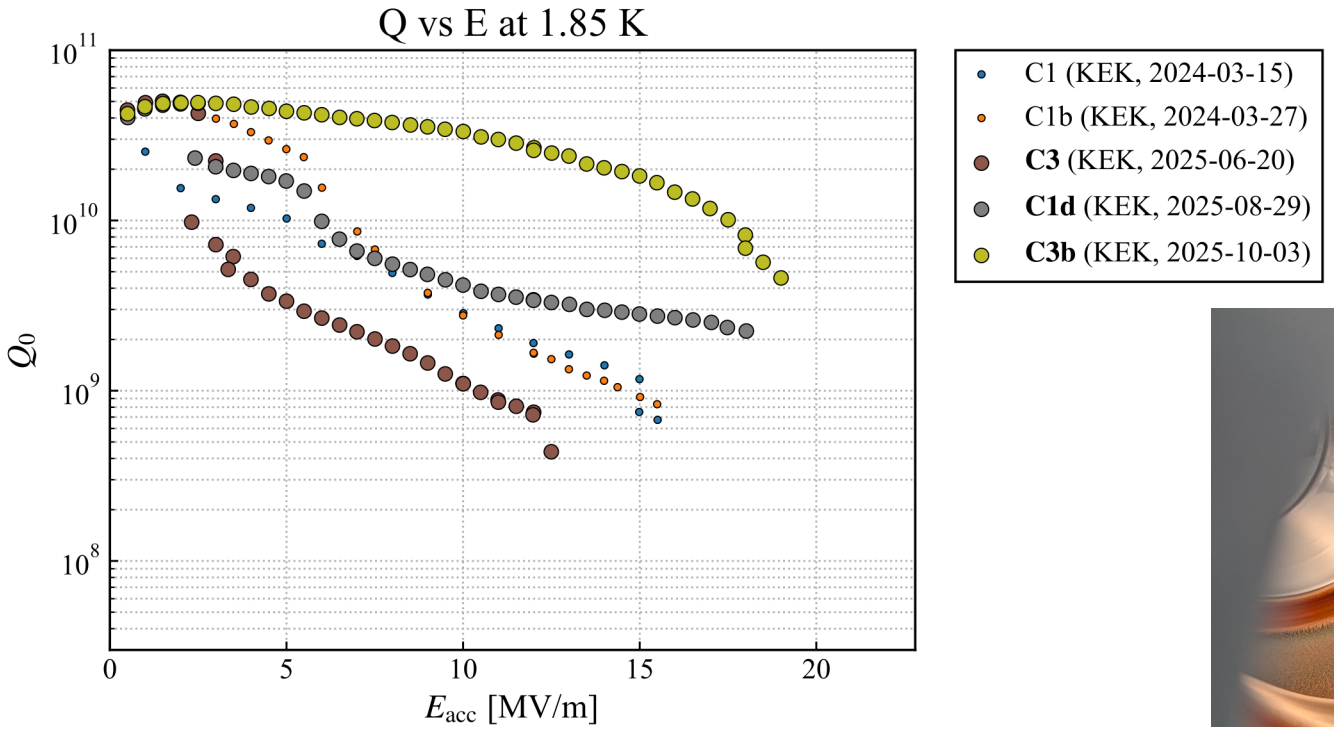


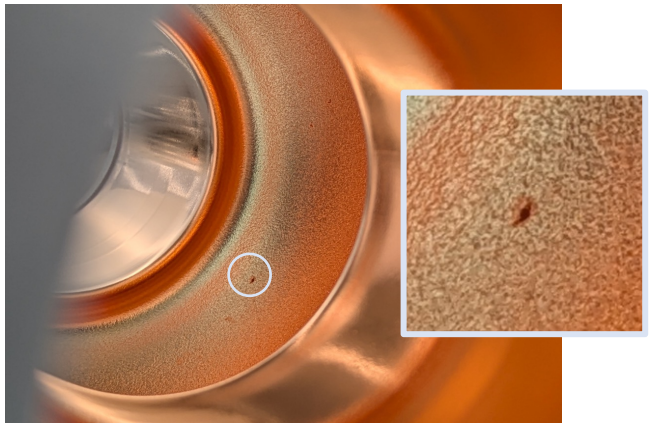




Small ΔT cooling is essential for bilayer structure cavities.

→ A simple “shield” is effective for vertical cryostat measurement.

# Substrate polishing



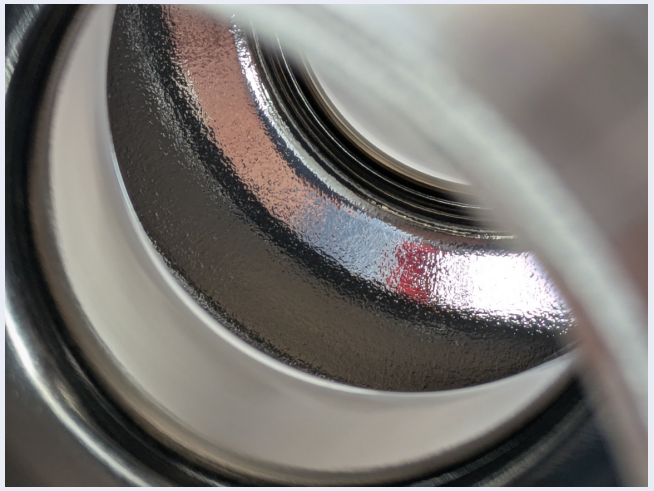
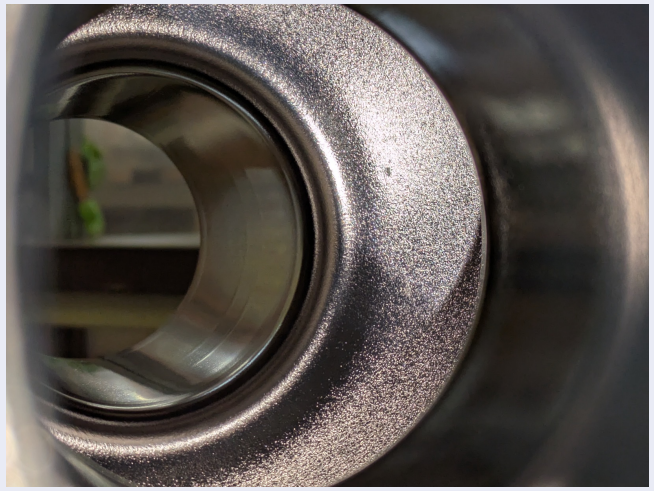
## C1d (2025-08)

- Plasma EP (~200 um) after HF
- Max. $E_{acc}$ was higher (18 MV/m) than C1/C1b
- Q-drop has occurred

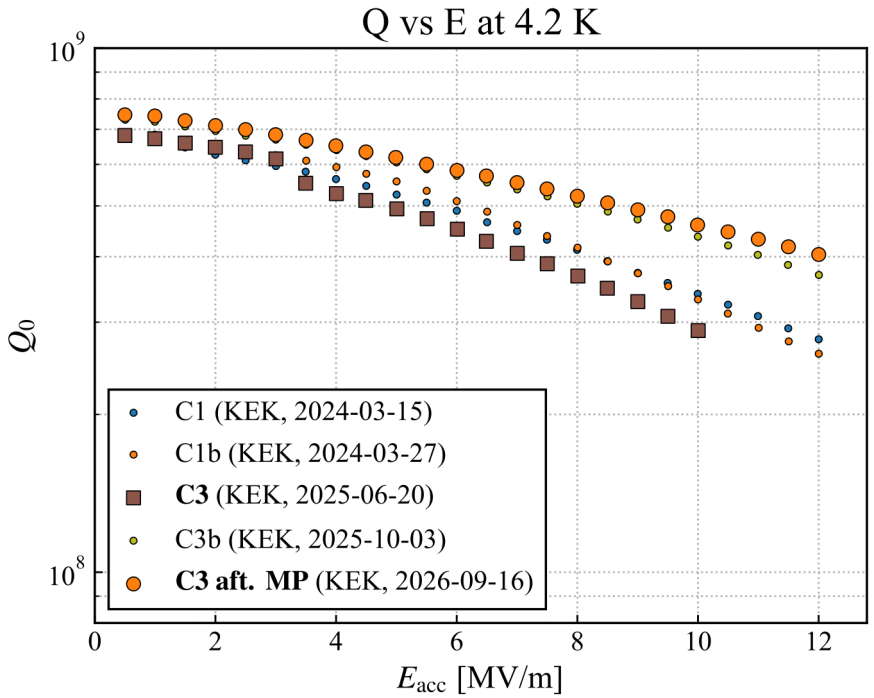
## C3 and C3b (2025-06 to 10)

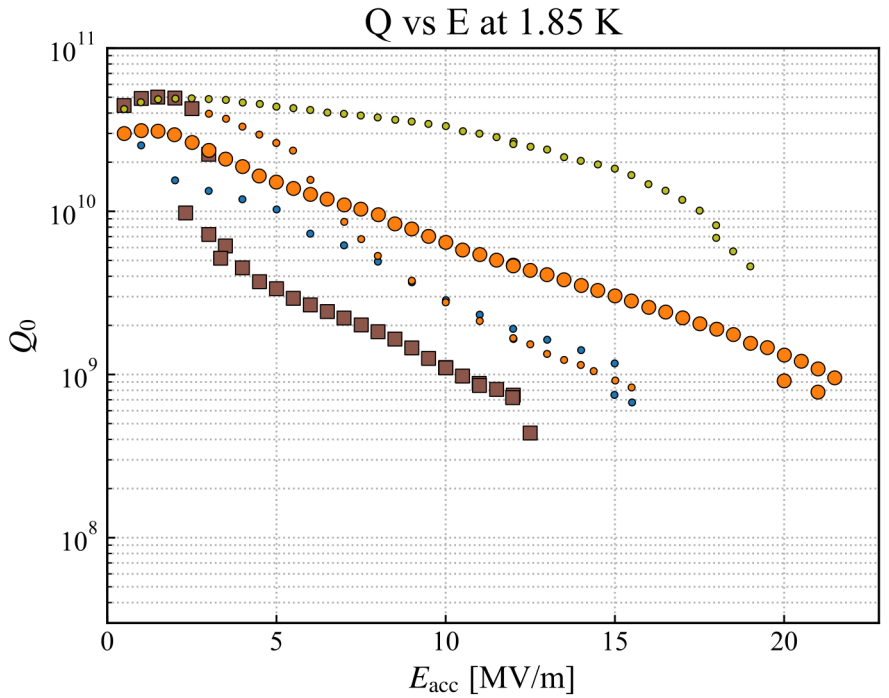
- Mechanical polishing + light EP before HF
- Two cavities received the same treatment
  - C3b kept **$Q_0 > 1\times10^{10}$ until 17 MV/m** (1.85 K)
  - C3 had Q-drop and steep Q-slope
    ← A locally oxidized spot on the substrate

# Surface condition comparison

| | C1, C1b | C1d | C3, C3b |
|---|---|---|---|
| **Treatment** | Baseline | **Plasma EP** ~200 um after HF | **Mechanical polishing** before HF |
| **Surface** |  |  |  |
| **Roughness (Ra)** | 3.3 um | **0.69 um** | 2.7 um |
| **$Q_0$ at 10 MV/m** | C1: 3 ×$10^9$<br>C1b: 3 ×$10^9$ | C1d: 4 ×$10^9$ | C3: 1 ×$10^9$<br>**C3b: 3 ×$10^{10}$** |

# Additional substrate polishing




## C3 after 2nd MP (2026-09)

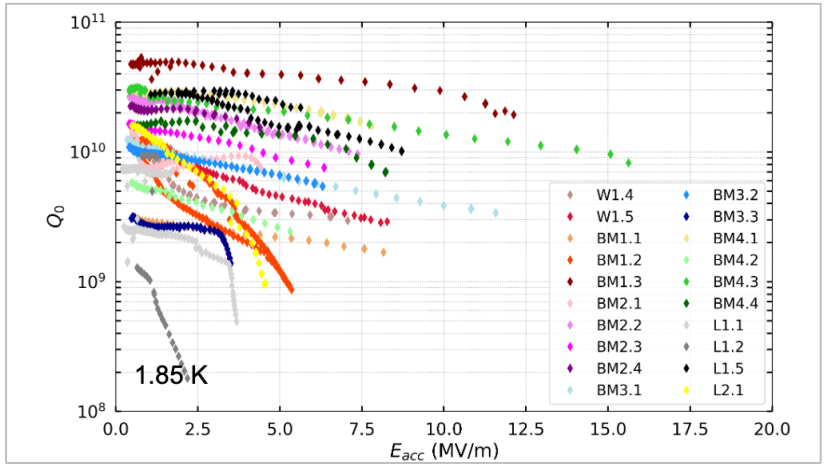
- Cu substrate had 2nd mechanical (buff) polishing followed by Nb re-coating.
- Q in low field was lower than before, but Q-drop did not occur.
- Quench field **21.5 MV/m** is the highest in our Nb/Cu cavities.
- **Target cleared**: $Q_0 > 4\times10^8$ at 12 MV/m, 4.2 K

# Discussion

## Recovery from Q-drop

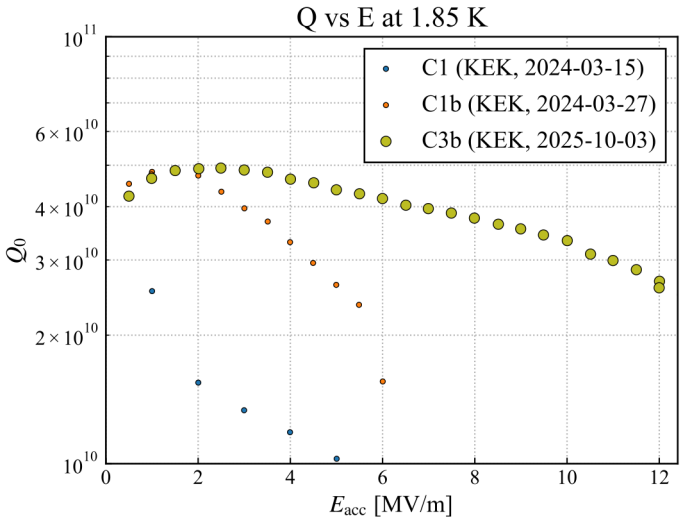
- Is “a local defect on substrate” the cause of Q-drop?
- Which stage of the manufacturing process is the cause of the defect?
  - In HF cavities, Q-drop occur more frequently than in other seamless cavities.
  - Copper material? Tube drawing? Hydrant? Coating preparation?
- Is it possible to recover from Q-drop using other polishing techniques?

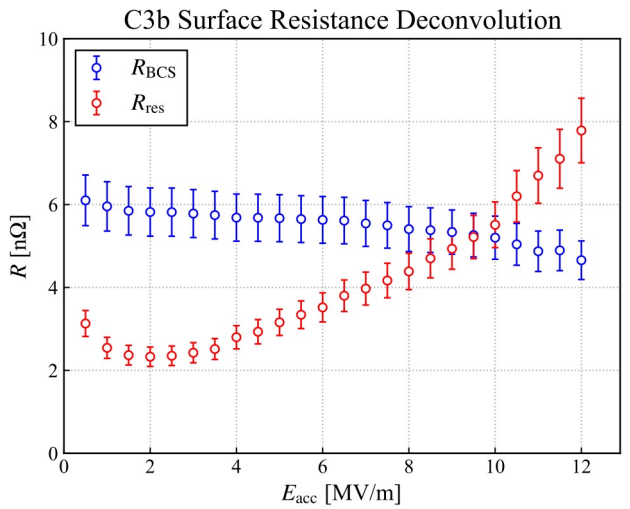
Kristof Brunner, TFSRF2024
https://indico.cern.ch/event/1376902/contributions/6111630/




## Nature of Nb film

- Anti-Q-slope? Dirty?
  - In low field (< 2 MV/m), the residual resistance decreases as $E_{acc}$ increases.
  - BCS resistance decreases up to 12 MV/m.
  - MFP of HiPIMS Nb film is shorter than that of ILC-treated bulk niobium.



# Summary

## Common features in our Nb/Cu cavities

- “Q-drop” frequently occurs.
- Spatial temperature gradient at Tc has strong correlation to the residual resistance.

## Substrate polishing

- At present, no relationship between surface roughness and RF performance can be confirmed.
  - One cavity kept $Q_0 > 1\times10^{10}$ until 17 MV/m with orange-peeled surface.
- “Q-drop” occurred in one cavity with locally oxidized spot on the substrate; however, this was recovered by mechanically polishing the substrate.
  - Max $E_{acc}$ reached 21.5 MV/m at 1.85 K, the highest in our cavities.
  - Our target: $Q_0 > 4\times10^{8}$ at 12 MV/m, 4.2 K was cleared.

## Acknowledgements