Fermilab

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PIP-II Cavities Qualification Challenges

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SSRs: The SSR2 Cleaning Challenge

- SSR2 cavities present a unique geometric challenge for SRF surface processing:
  - **Complex Geometry**: Re-entrant surfaces trap contaminants during fabrication.
  - **RF Volume Access**: Conventional HPR struggles to reach all internal zones.
  - **Processing History**: Years of multi-institutional effort to refine the "Recipe" for FE-free surfaces.

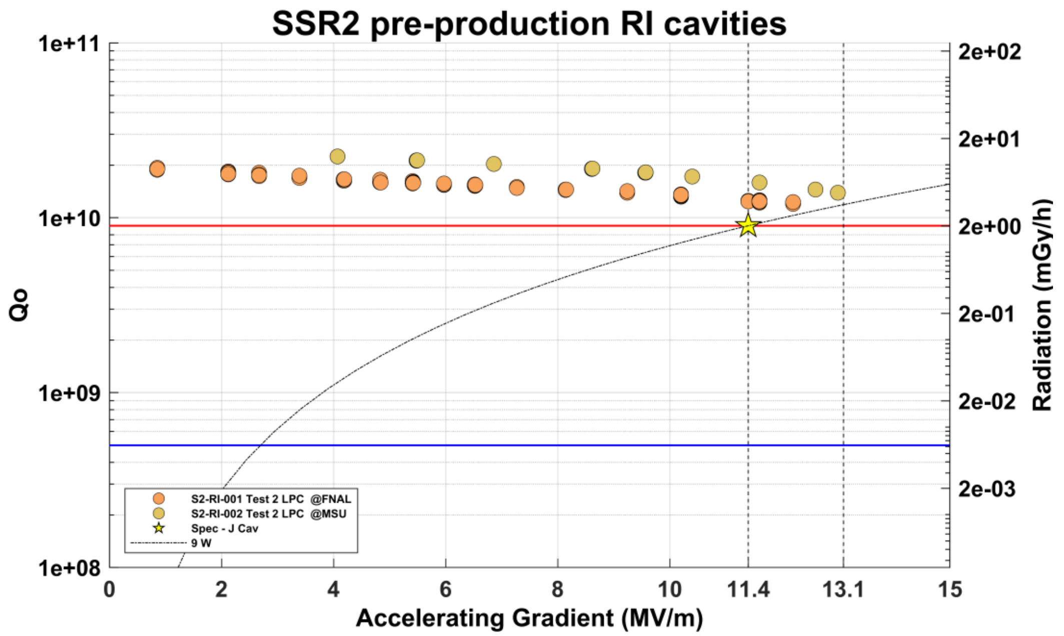
- At last TTC (April 2025) we had 2 FE free cavities out of the 5 required for string assembly achieving the required Q0 and Accelerating Gradient that were the result of years-long effort leading to a final "processing recipe".
- Since then we succesfully qualified the remaining 3 cavities and we went on qualifying 2 additional spare cavities that are going to be integrated in future cryomodules.

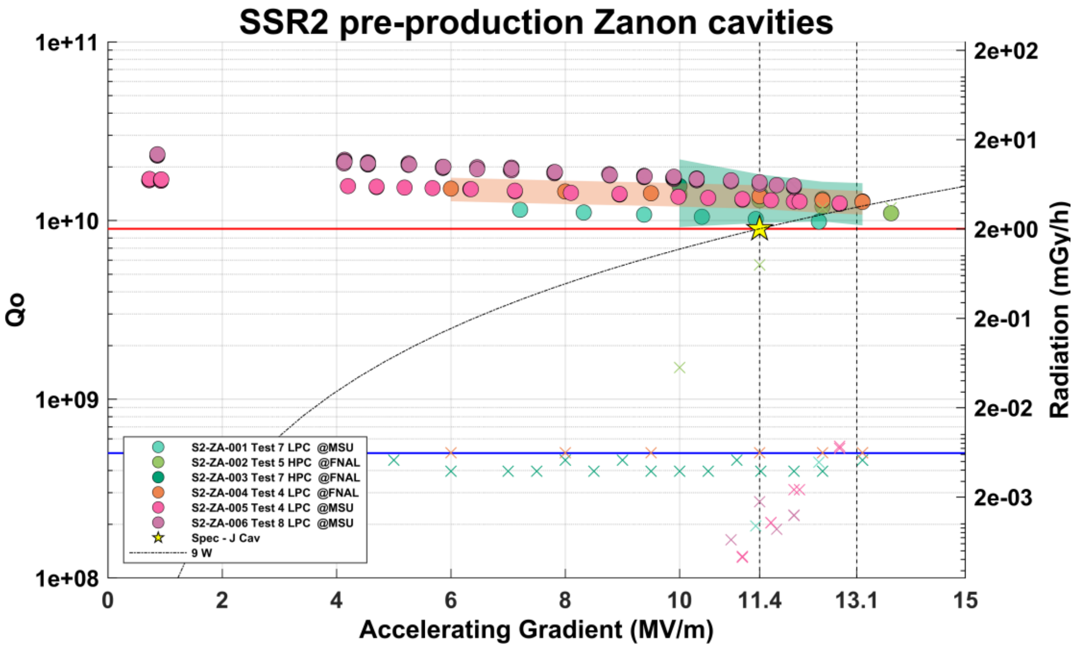
Pre-production SSR2 Cavity and Magnet String Completed using 5 FE Free Cavities

SSRs: The SSR2 Cleaning Challenge

The "new" updated recipe:

- Robotic HPR @MSU
- Manual cleanroom assembly + slow pump down and leak check
- ~~120C Bake to mitigate multipacting~~
- Slow Venting + high flow purging through the DN40 RAV equipped with a filter
- Assembly of HPC performed with the UR16 cobot @FNAL
- No blowing of the holes while removing the bolts on the unity coupler
- Slow Pump down
- No active pumping during cold testing





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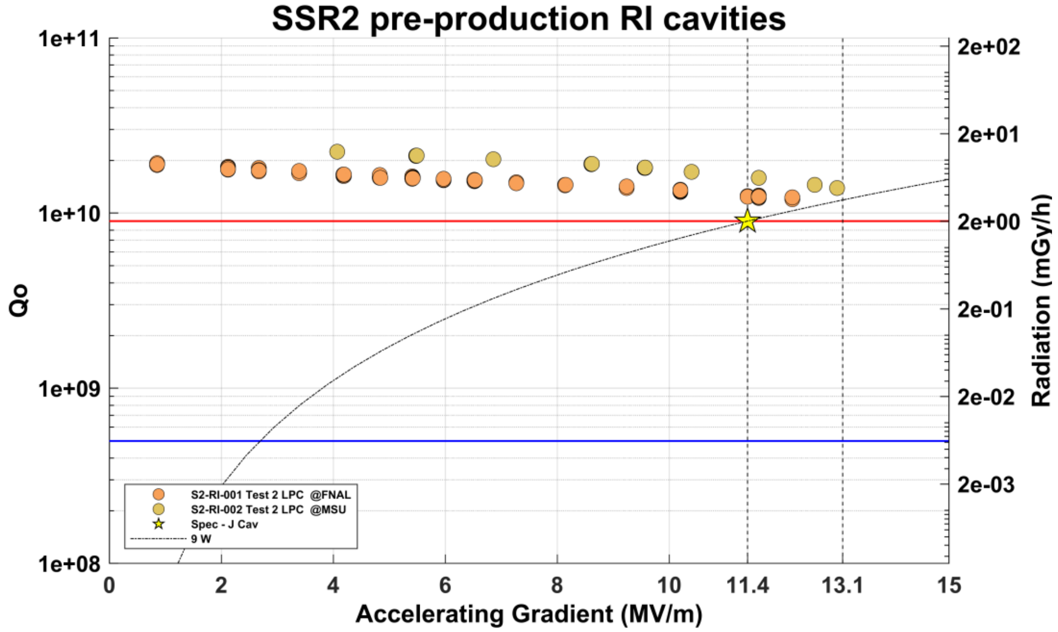
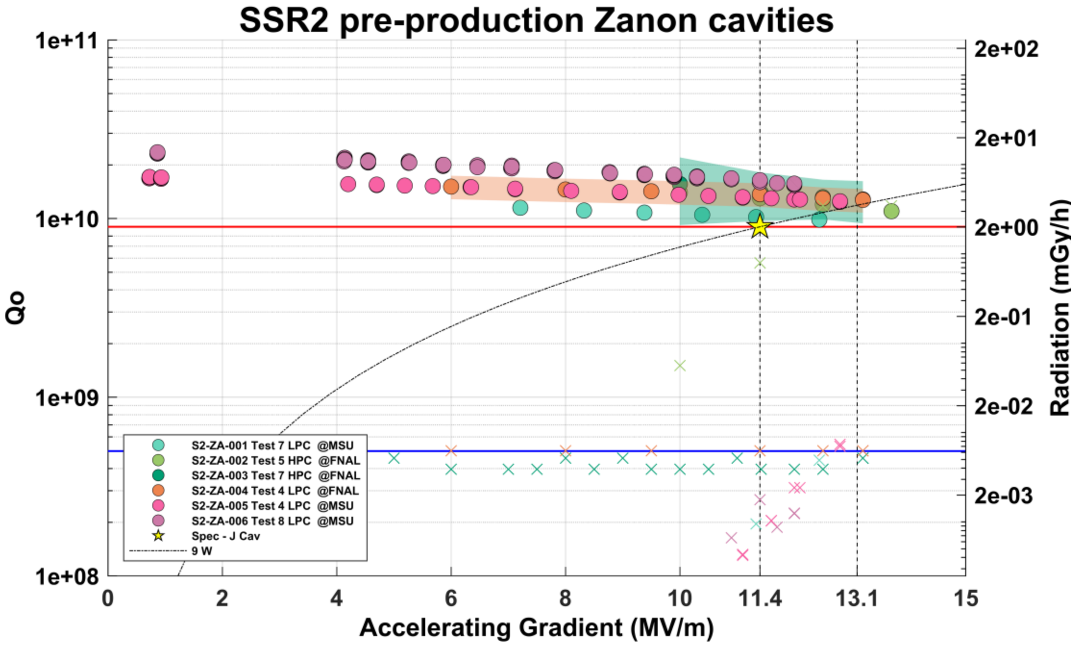
Most of the cavities had oxidation marks due to HPR process. Ultimately. we can say that this is not cause for FE





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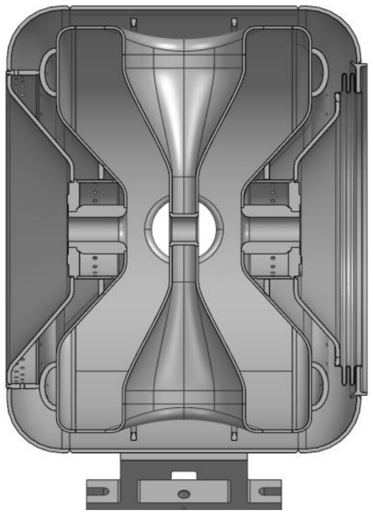
SSRs: SSR1 Cavities

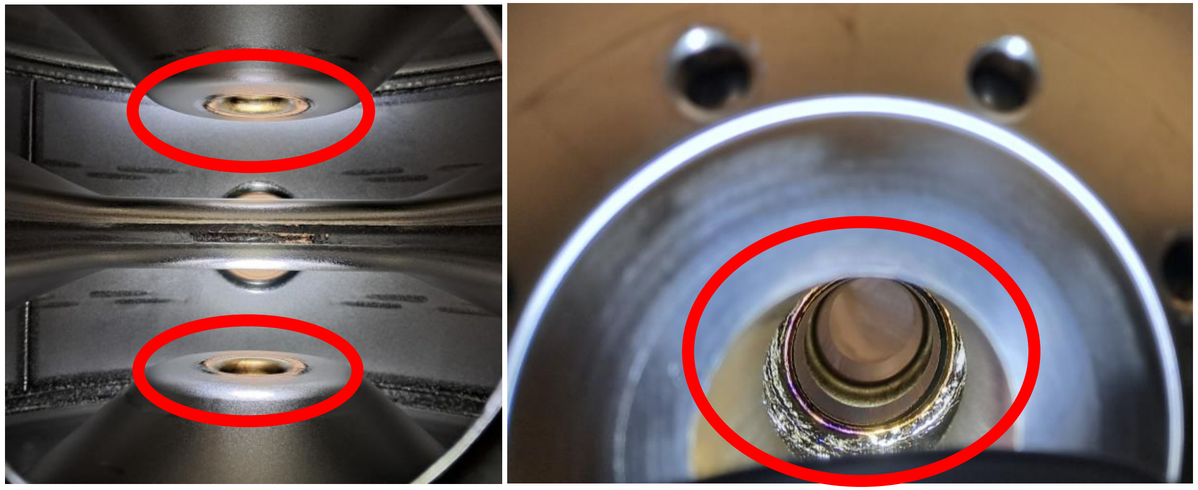
The "starting" recipe – start early to mitigate FE :

Bare cavity received final HPR after bulk BCP, Heat Treatment and light BCP

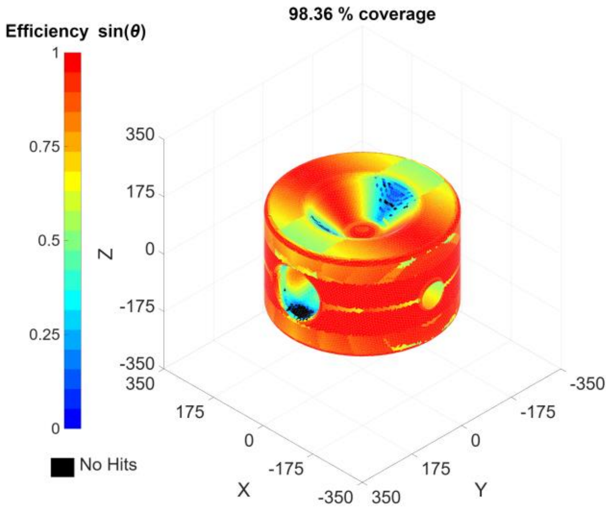
- Long – conventional HPR @Zanon using IJCLab developed nozzle head
- Manual cleanroom assembly + slow pump down and leak check
- 120 Bake – 24 hours
- Sent to FNAL for cold testing



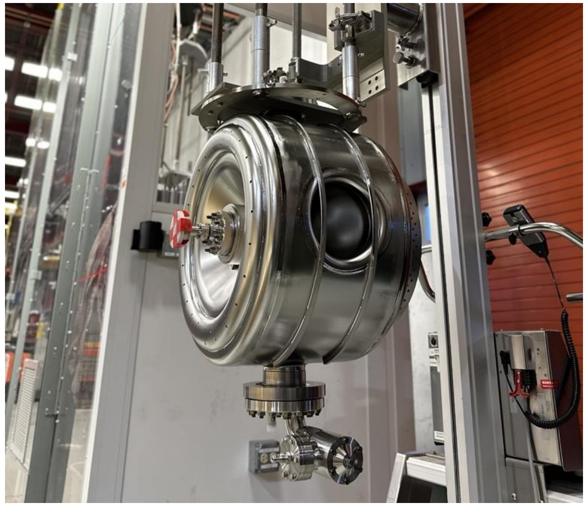
SSR1 Cavity Section: compared to SSR2, conventional HPR should be capable of effectively rinsing the cavity RF surface



Yellow-ish – Purplish color is visible near the beam and spoke pipes is a sign of oxidation due to the HPR process and was visible post HPR --> Nitric acid rinsing was initially employed to get rid of it



HPR Coverage and Efficiency is promising from simulation



Bare SSR1 S1-ZA-001 at Fermilab to VTS testing. Test failed due to cold leak.

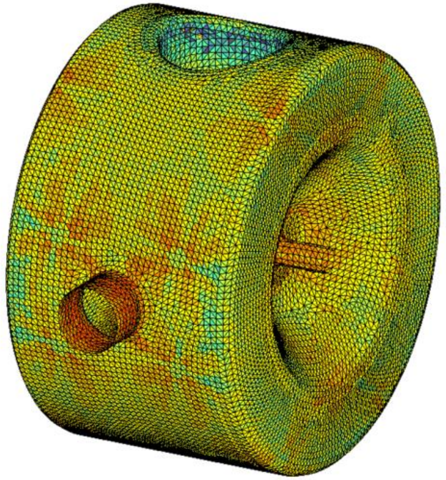
SSRs: SSR1 Cavities

The "final" updated recipe:

- Robotic HPR @MSU
- Manual cleanroom assembly + slow pump down and leak check
- 120 C Bake for 24 hours
- Slow Venting + high flow purging through the RAV equipped with a filter
- Assembly of HPC performed with the UR16 cobot @FNAL
- Blowing of the holes while removing the bolts on the unity coupler
- Slow Pump down
- No active pumping during cold testing

S1-ZA-001 with vacuum side HPC @FNAL after cobotic assembly

Robotic HPR - courtesy of Kyle Elliott, MSU



Virtual 100% coverage provides the best possible rinse – courtesy of Blake Gower, MSU

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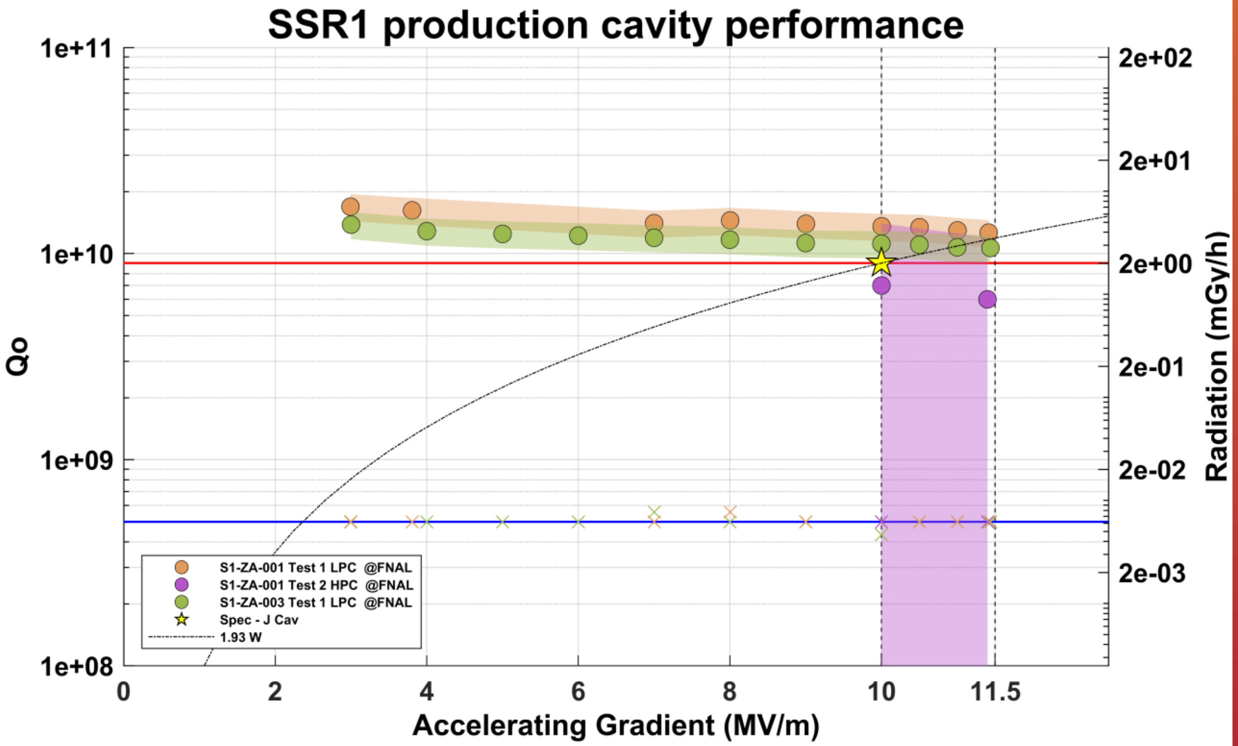
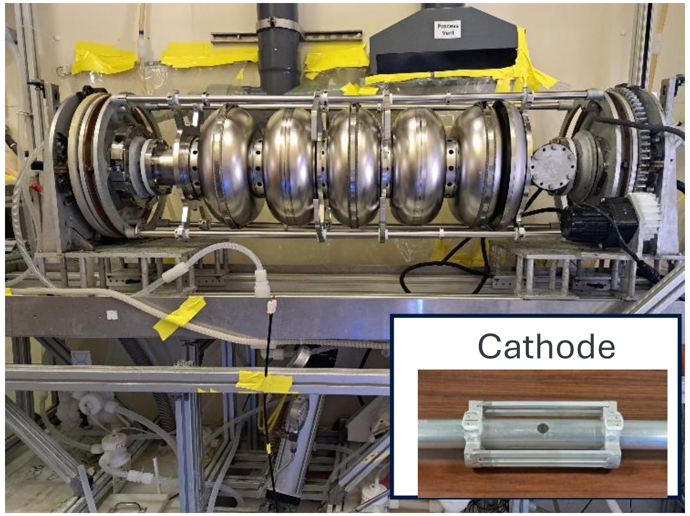
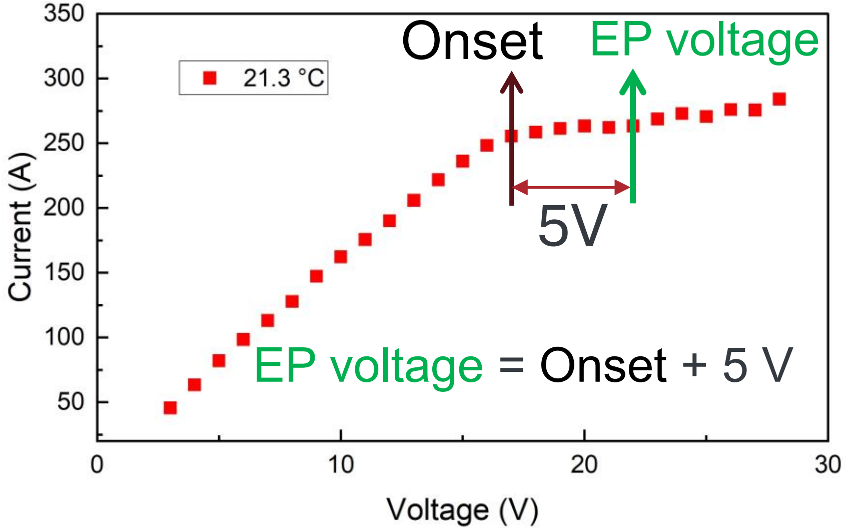


650 MHz: Main challenges

- EP optimization for B61 and B92
- Transfer of EP and N2 doping technology to industry
- Study of defects through replica leading to manual local grinding and 60 um EP reset
- Field emission mitigation:
  - spray head optimization effort
  - Cobot assembly after HPR

650 MHz: Rough Equator Surface

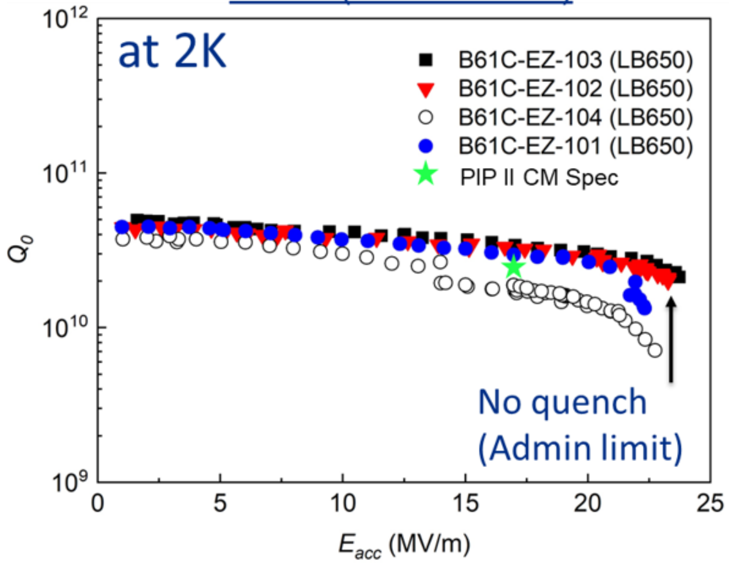




Parameters	Initial EP	Modified EP	
	Warm/cold EP	*Warm EP*	*Cold EP*
Voltage	18 V	20-25 V	16-22 V
Cavity temperature	22 °C/12 °C	22-25 °C	12 °C
Cathode type	Cathode-I (initial)	Modified cathode with large surface area	

V. Chouhan et al., Nucl. Instrum. Methods Phys. Res. A 1051 (2023) 168234
V. Chouhan et al., **TUPTB041, TUPTB042** SRF2023.

LB650 (5-cell cavities)

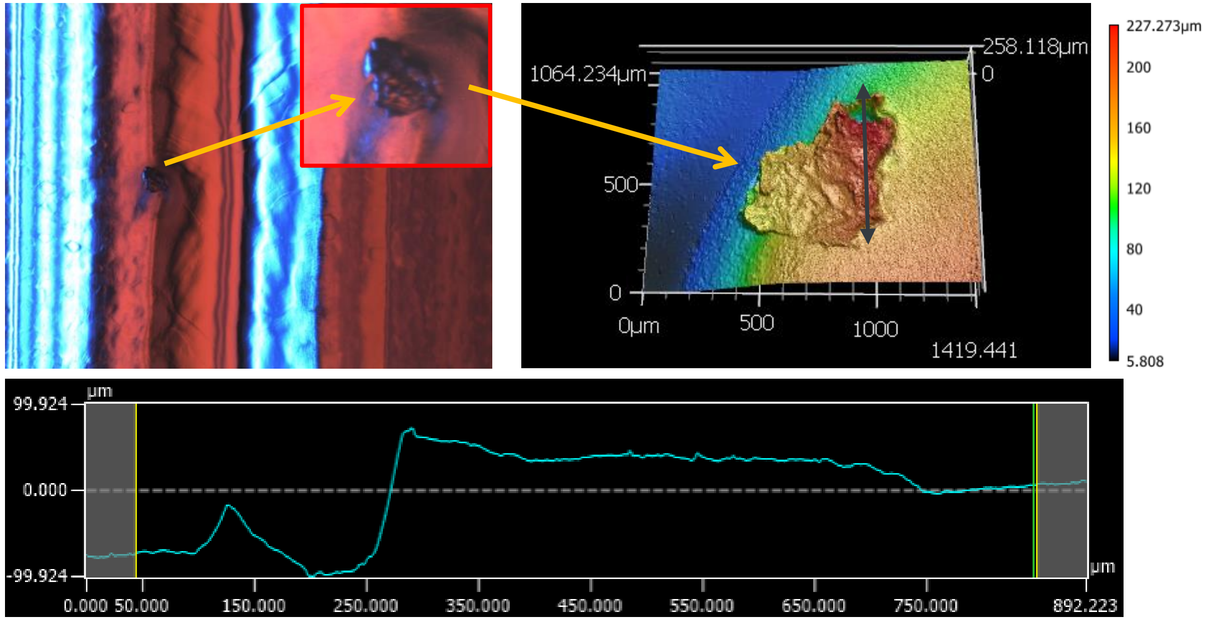


- Optimized EP resolved issues of rough equator surface and premature quenching of the cavities.
- Both LB650 and HB650 cavities met gradient specifications.
- R&D cavity with the optimized cathode and EP conditions showed >50 MV/m (V. Chouhan et al, THPB028, LINAC2024).
- Baseline EP, N-doping, and post N-doping EP protocols were transferred with partner labs and vendor.

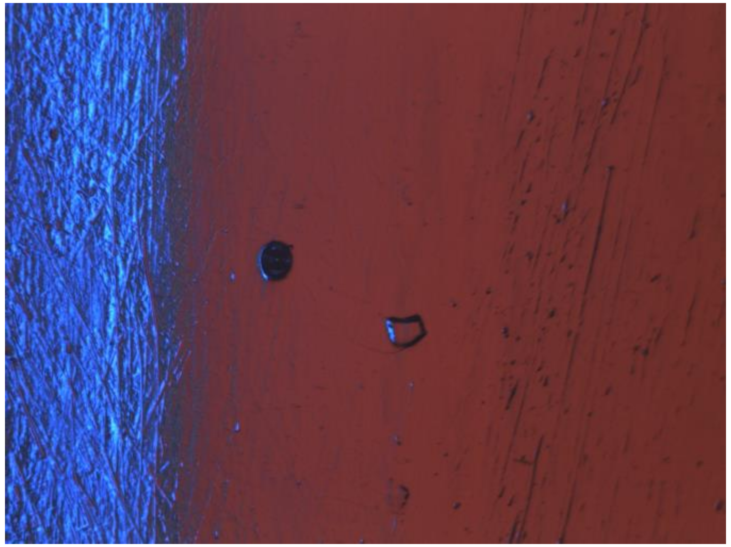
650 MHz: Surface Defects

- A defect was found on the LB101 equator after EP. The cavity after EP prematurely quenched at 20 MV/m. Manual grinding followed by EP was applied.
- A few HB650 cavities processed at Zanon were also found with surface defects and were treated with local manual grinding and 60 µm EP reset.

LB650: B61C-EZ-101



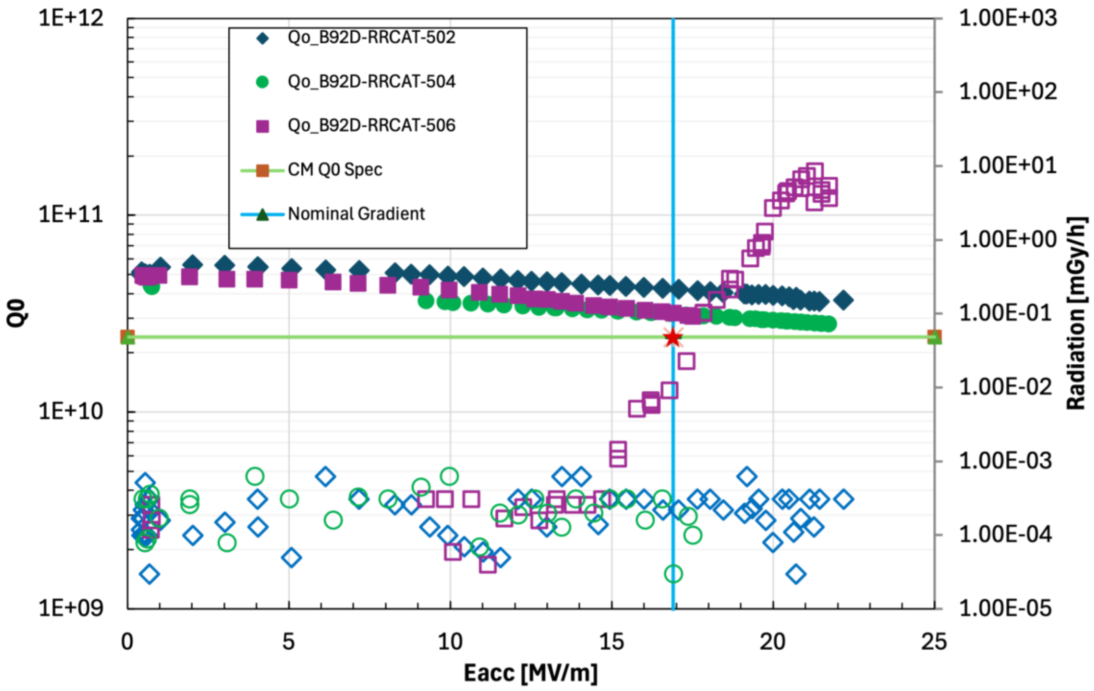
HB650: B92D-RRCAT-502



650 MHz: prototype B92 Cavities

- Cavities from prototype cryomodule were processed with HPR and tested.
- Three pre-series cavities B92F-RI-201, B92F-RI-202, and B92F-RI-203 were also re-HPRed at UKRI and tested.
- 13 cavities are qualified. B92D-RRCAT-506 quenched at lower field of 17.5 MV/m.

Serial Number	Status
B92M-ZRI-301, B92M-ZRI-302, B92M-ZRI-303, B92M-ZRI-305, B92M-ZRI-306, B92M-ZRI-307, B92M-ZRI-308, B92M-ZRI-310	Qualified
B92D-RRCAT-502	Qualified
B92D-RRCAT-504	Qualified (0.01 mGy/h at 18.8 MV/m)
B92D-RRCAT-506	FE-free, limited at 17.5 MV/m
B92F-RI-201	Qualified
B92F-RI-202	Qualified
B92F-RI-203	Qualified



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