Guided Cavity Repair with Laser, E-Beam and Grinding

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Recent cavity processing statistics indicate that the development of RF superconductivity has reached a stage where more and more cavities were limited by quench and not by field emissions. The combination of high resolution optical inspection, cavity quench detection and surface replica revealed more than half of the cavity quenches were limited by identifiable surface features, namely pits or bumps. The quench field ranged from 12 MV/m up to 42 MV/m.

Several methods have been explored in various laboratories to remove the surface features. Those included the laser re-melting, Electron beam re-melting and local mechanical grinding. This paper reports the latest development of those guided repair technologies and their benefits to improve cavity performances.

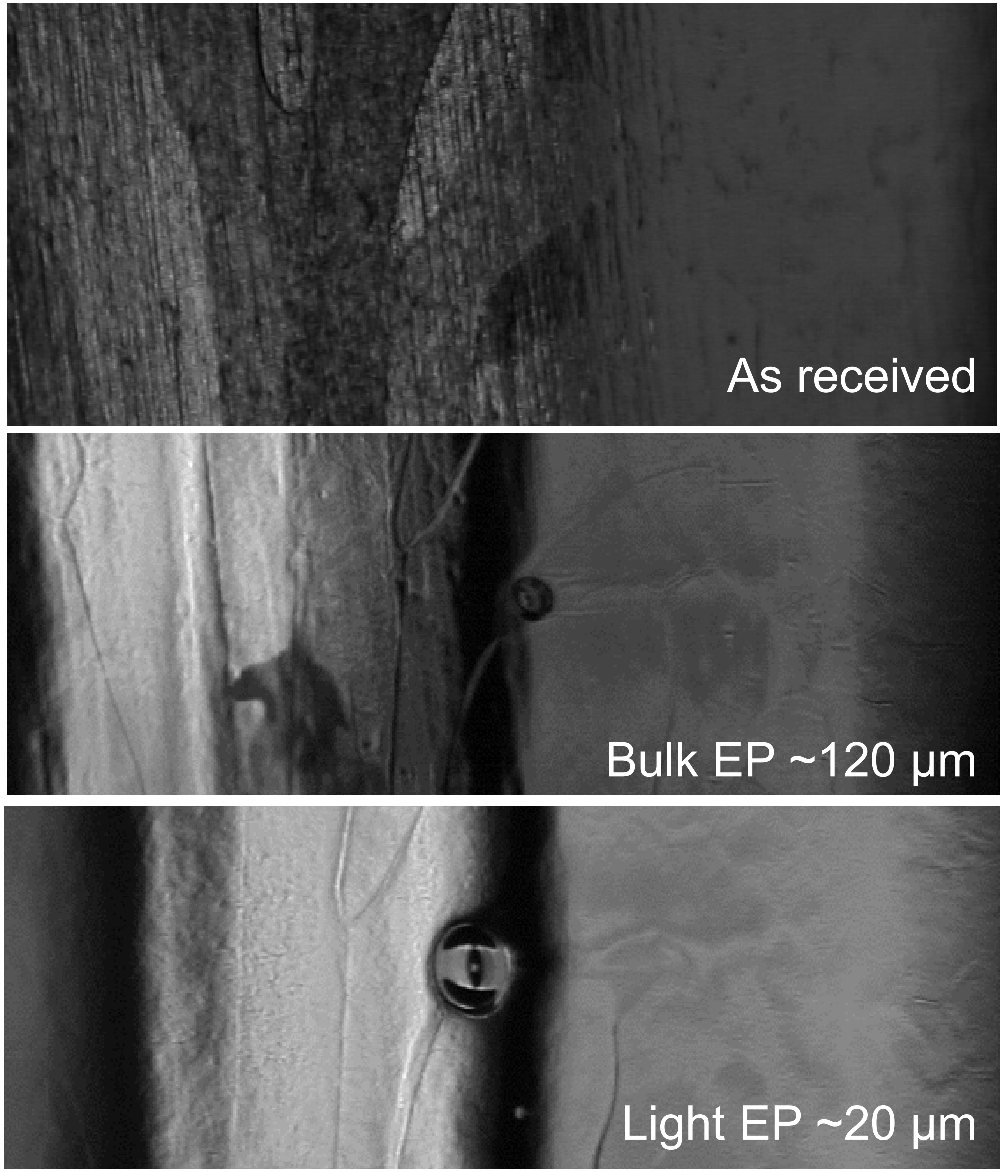
Outlines

- Motivation: the cavity performance limitations
- Laser melting (Fermilab), ***THPO015, THPO051***
- Electron beam re-melting (JLAB and Cornell), ***TUPO029***
- Mechanical grinding (KEK, Cornell), ***WEIOB02***
- Summary

Topics not covered:

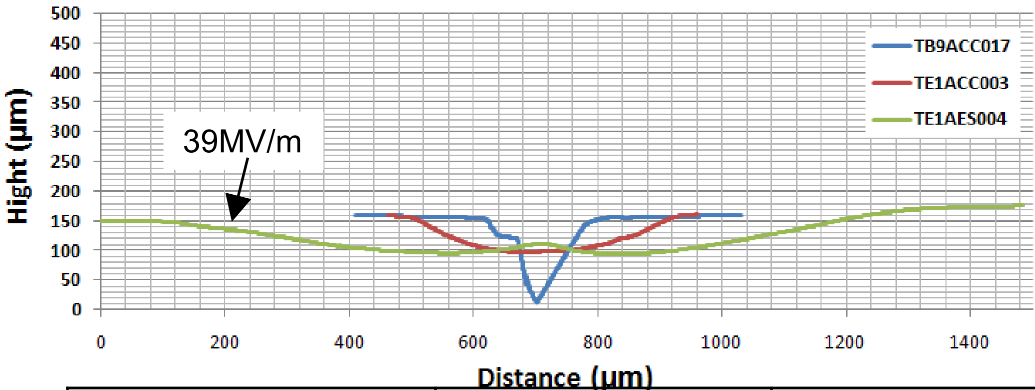
- Tumbling in an individual cell of a multi-cell cavity pursued at Cornell University
- Manual mechanical grinding

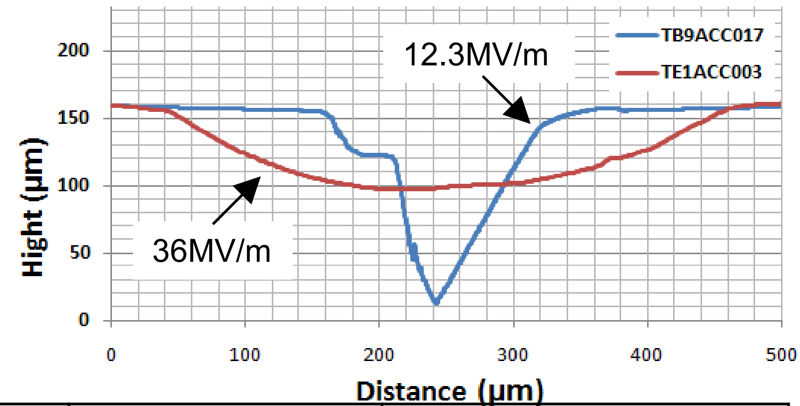
Exposure of weld void by continued EP



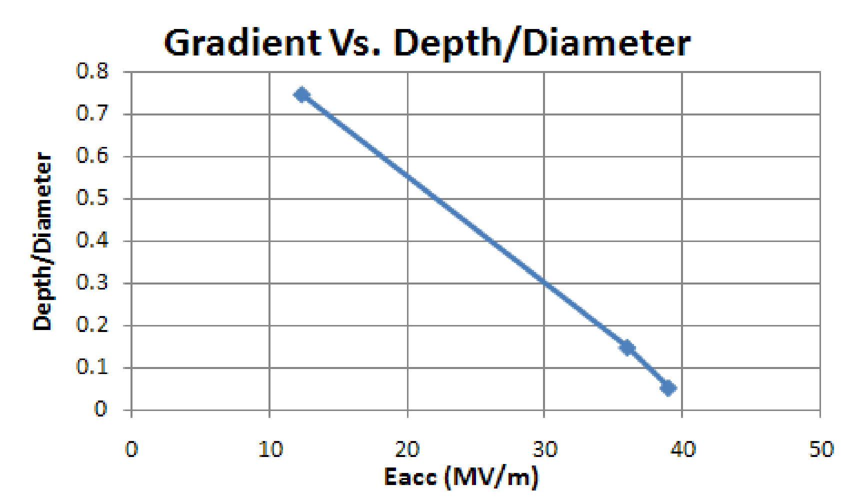
Courtesy of D. Sergatskov of Fermilab

Pits geometry and cavity RF performance





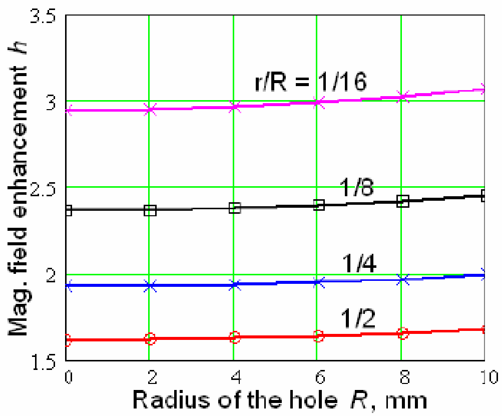
Cavity	Eacc (MV/m)	Diameter (µm)	Depth (µm)	Depth/Diameter
TB9ACC017	12.3	200	150	0.75
TE1ACC003	36	400	60	0.15
TE1AES004	39	1300	70	0.054

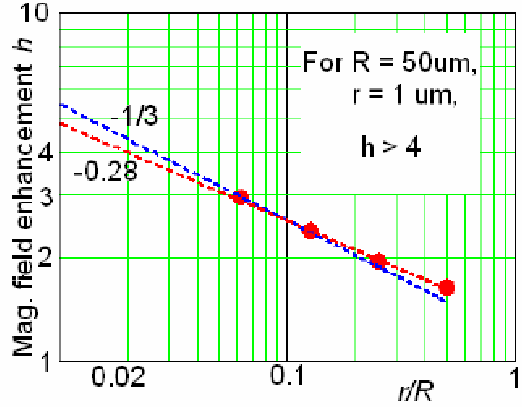


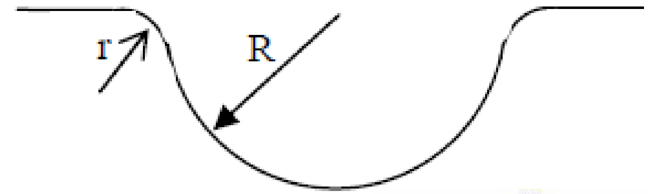
When the pit is very deep, the risk of trapping acid water is very high. Smoothening out these geometric defects can have strong benefit for chemical polishing and reduce field enhancement.

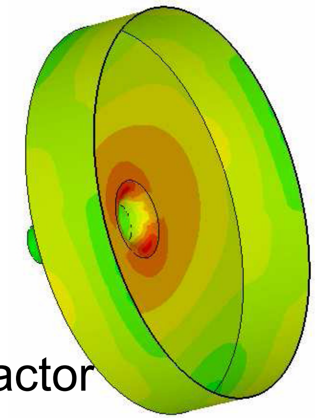
Summarized by M. Ge of Cornell University

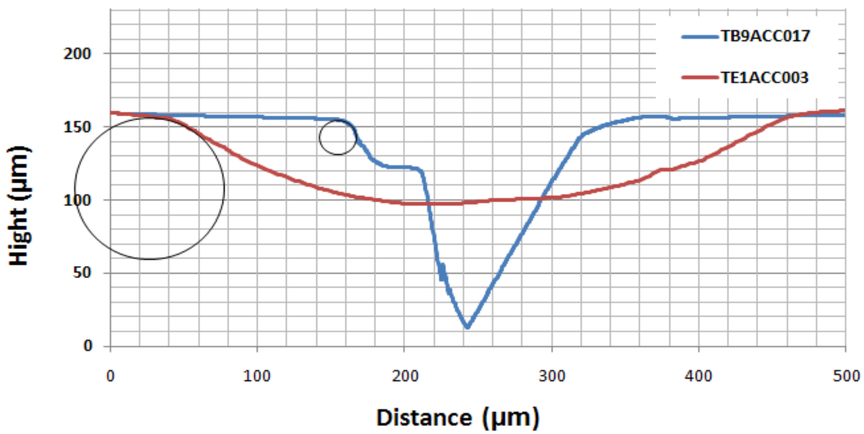
Field enhancement factor with r/R model











$$h_{meas.} = \frac{H_{rf,critical}}{E_{acc} \cdot \frac{H_p}{E_{acc}}}$$

h : field enhancement factor

Some defects are purely geometric while others are more than geometric.

Hrf,critical ~= 180mT, Hp/Eacc=4.26 mT/(MV/m)

	r/R	*h* simulation	*h* meas.
TB9ACC017	≈0.14	≈2.2	≈3.4
TE1ACC003	≈0.23	≈1.8	≈1.17

V. Shemelin, H. Padamsee, “Magnetic field enhancement at pits and bumps on the surface of superconducting cavities”, TTC-Report 2008-07, (2008).

Fermilab

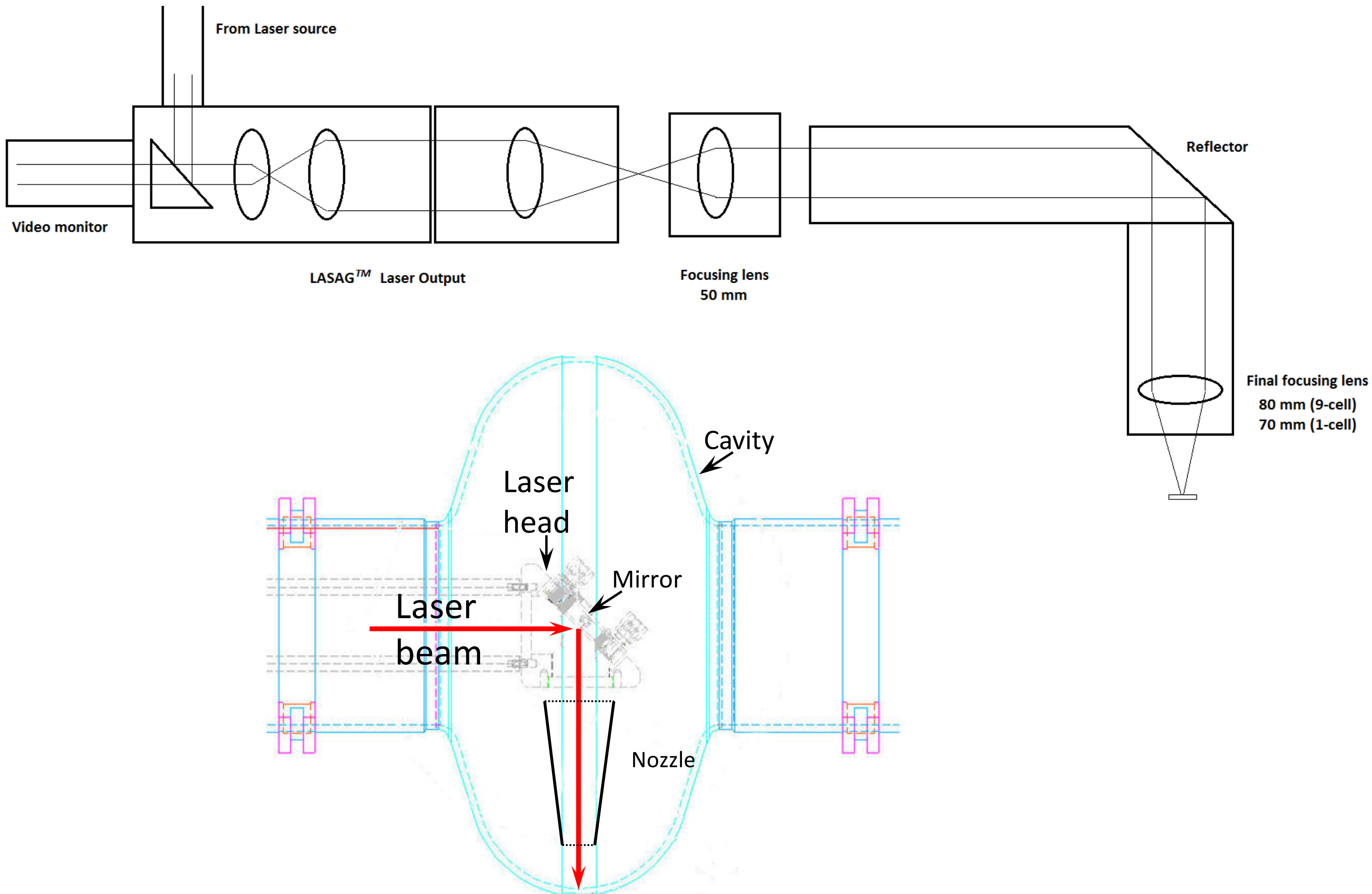
Visible cavity defects

- Defects can be deep and exposed later
- Defects can be purely geometric
- Defects can be intrinsic material related
- Defects can be both geometric and intrinsic

Motivation

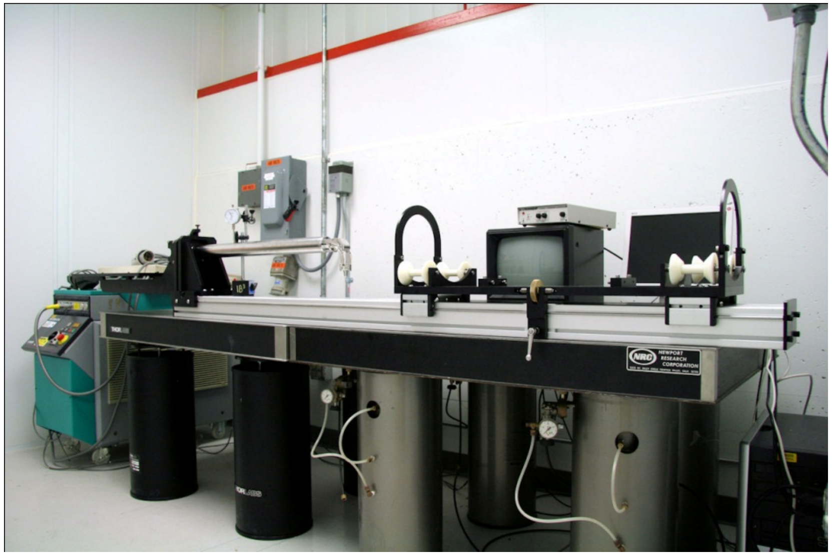
- Repair a cavity in a most cost effective way
  - Initial equipment cost
  - Operating cost
  - Post repair processing cost
- Repair a cavity without exposing more defects
- Repair cavities earlier in production flow

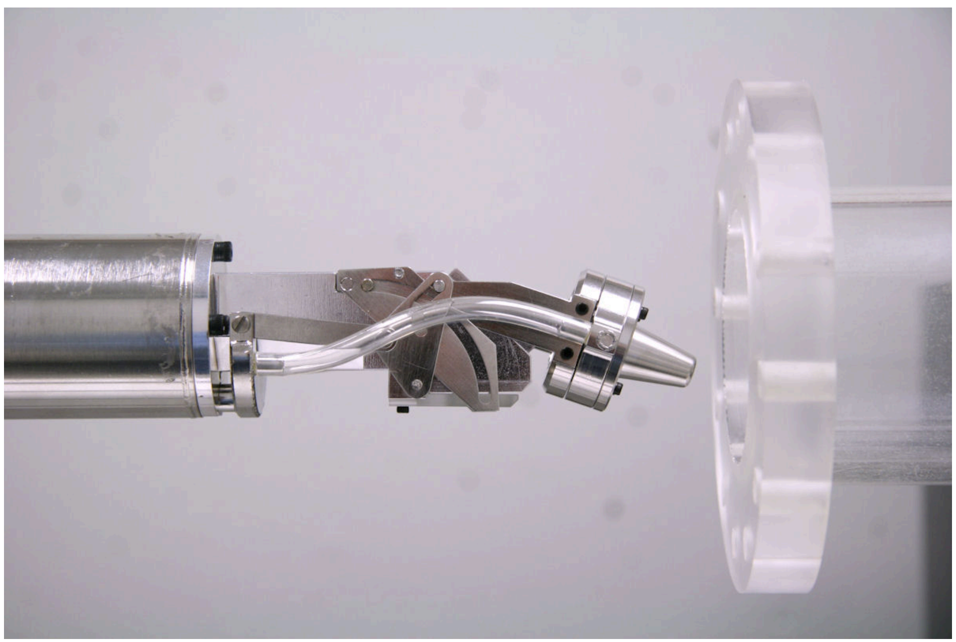
Laser melting system schematics

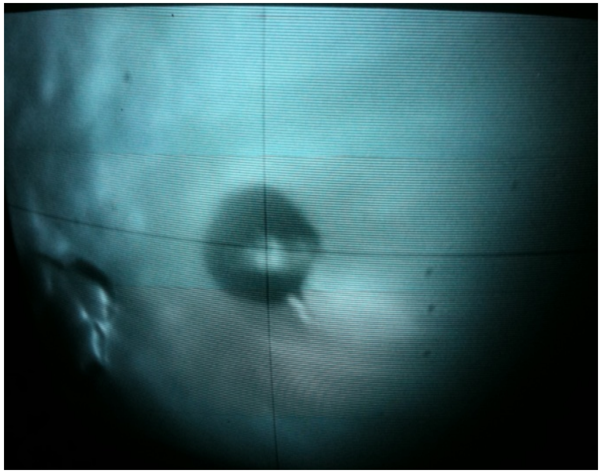


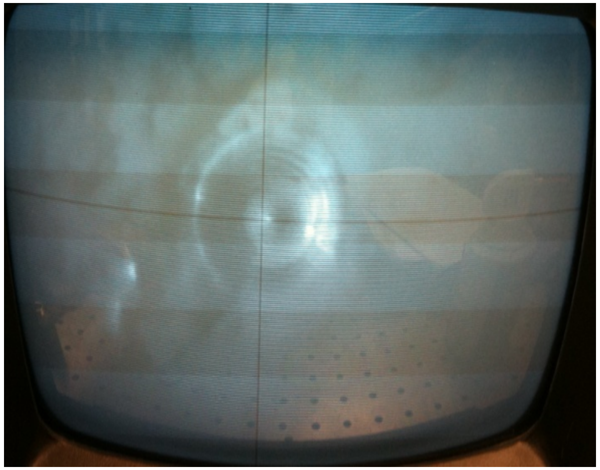
M. Ge, G. Wu, J. Ruan, T. Nicol, L. Cooley and R. Kephart
USPO, “Laser Melting Repair of Superconducting Niobium Cavities”

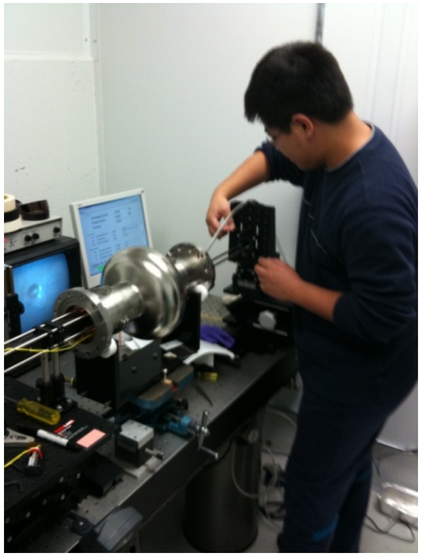
Laser melting system



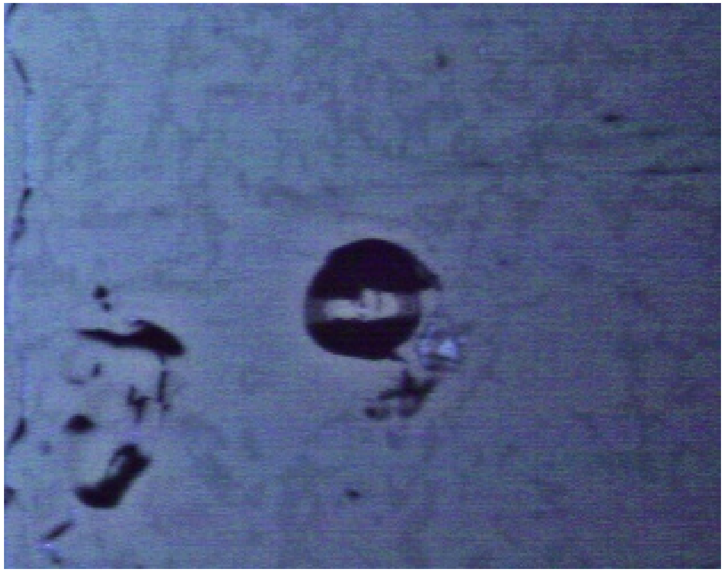




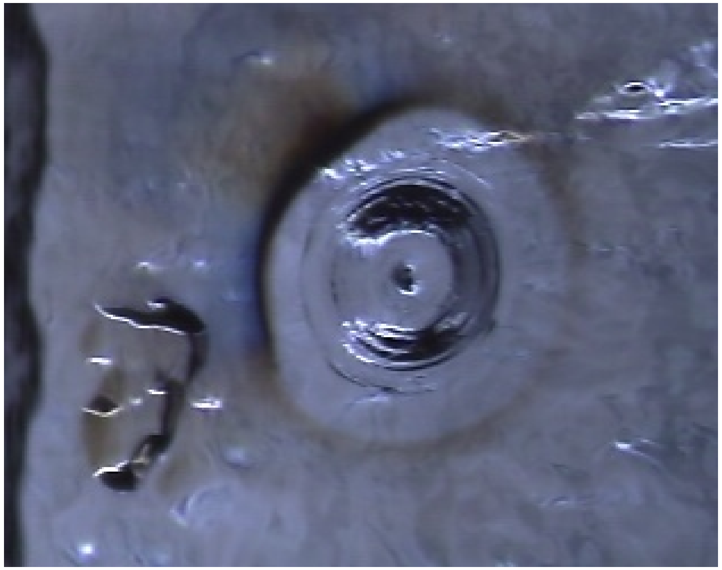




Screenshot of the monitor before and after laser re-melting

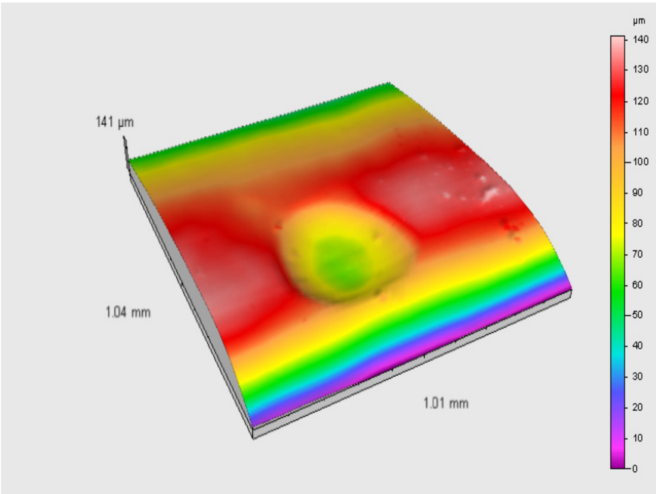


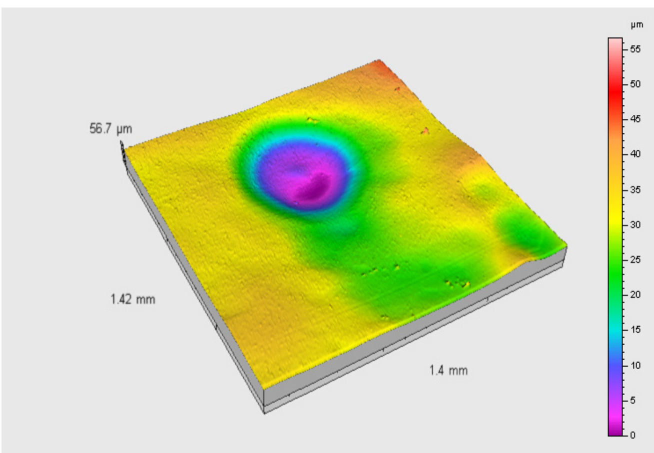
The optical image before re-melting



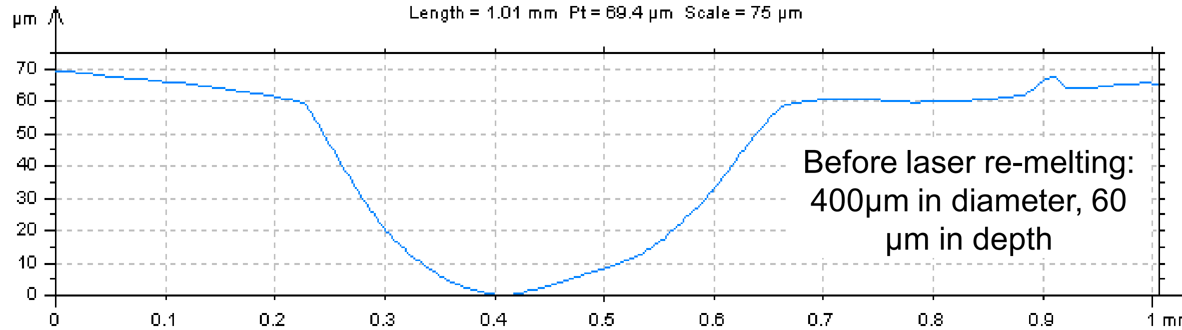
The optical image after re-melting

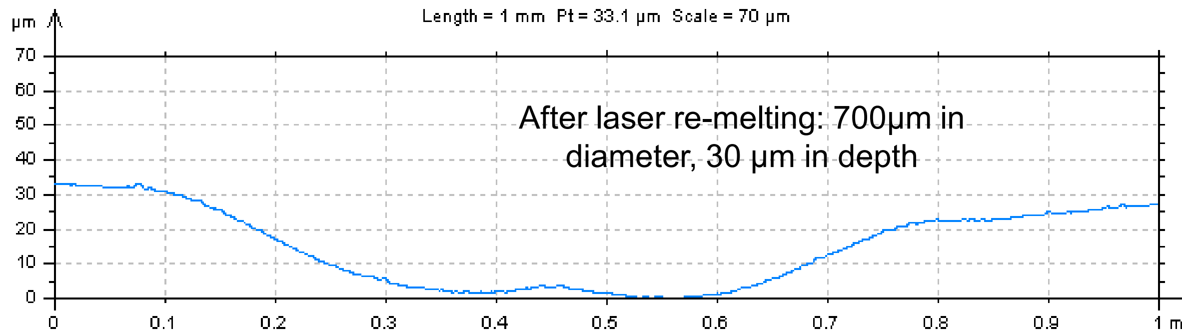
Profile comparison before and after Laser processing

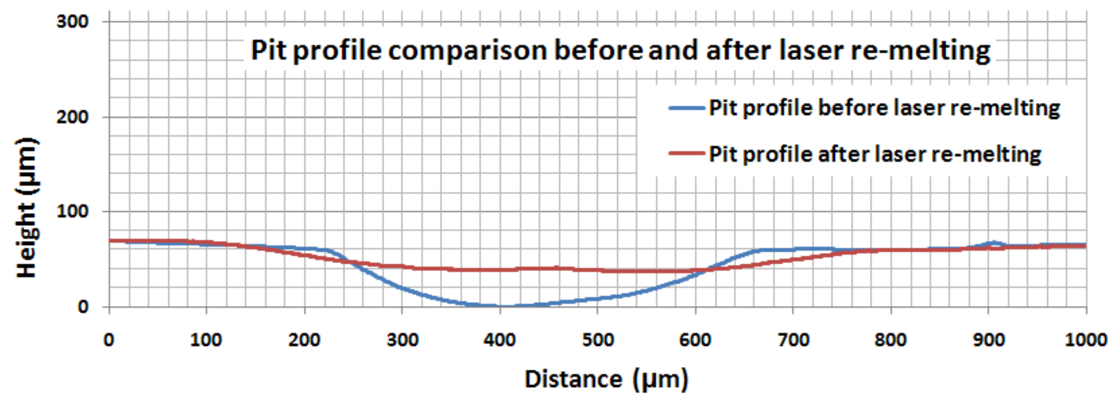




The pit profile changed from 60µm deep to 30µm flat after re-melting and 50µm light EP

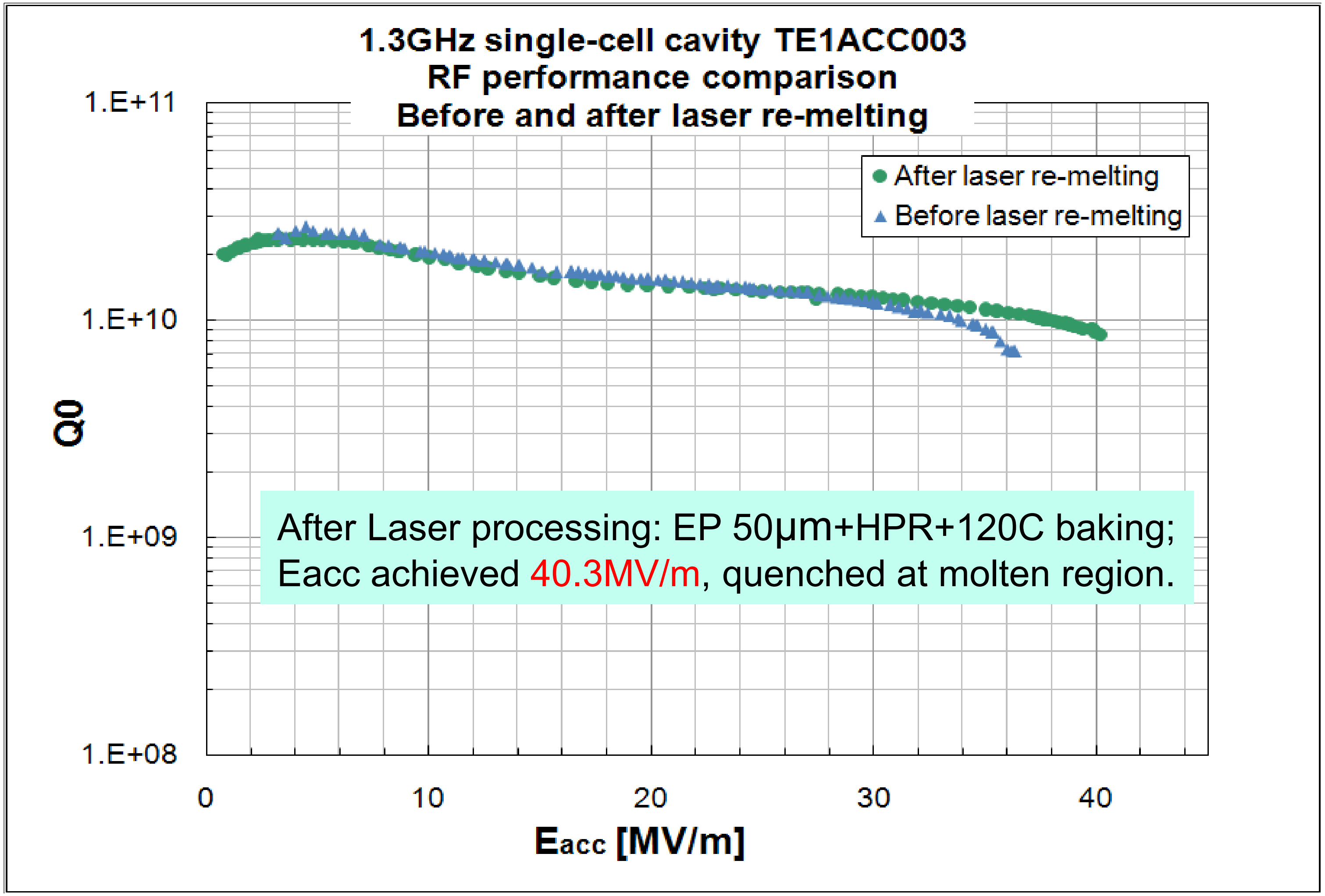






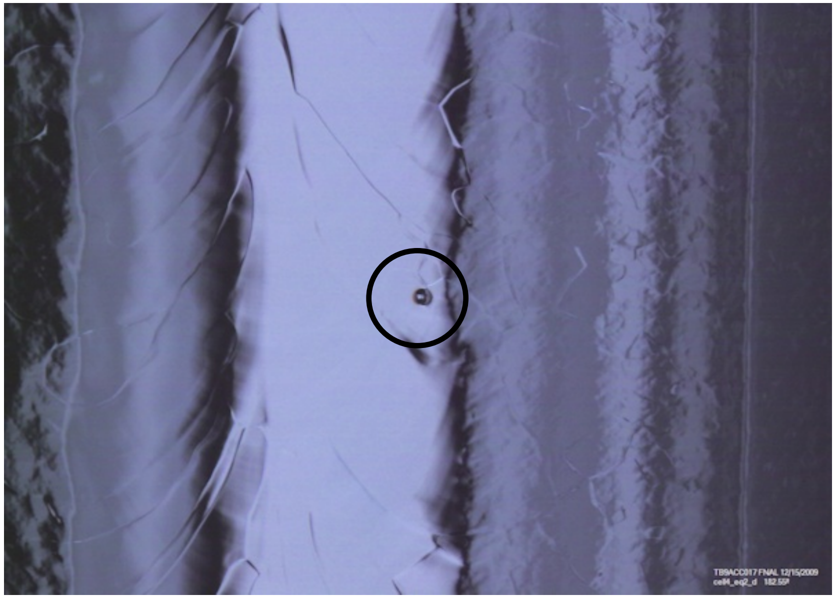
Results obtained through in cavity replica

Laser melting cavity RF test results

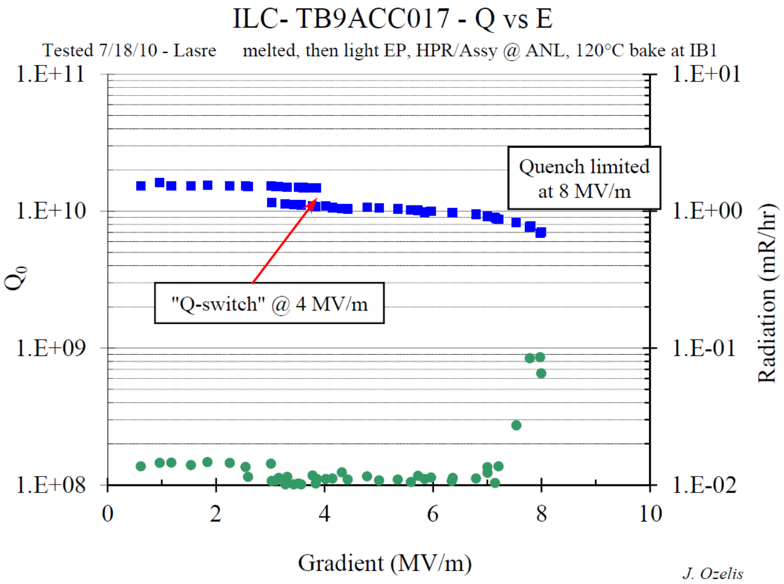


9-cell laser melting system

- Gas purging has longer distance compared to 1-cell system
- 9-cell system added rotational head compared to 1-cell system



Pit in 1.3GHz 9-cell cavity TB9ACC017
Quenched at 12.3MV/m.

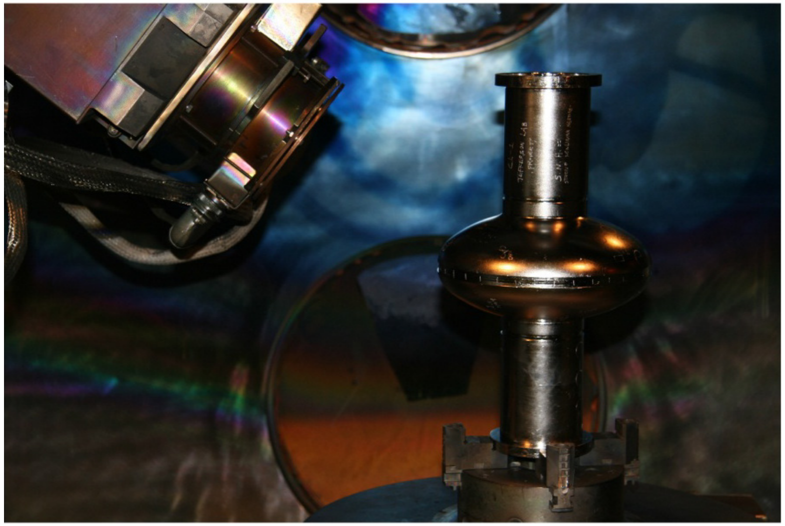


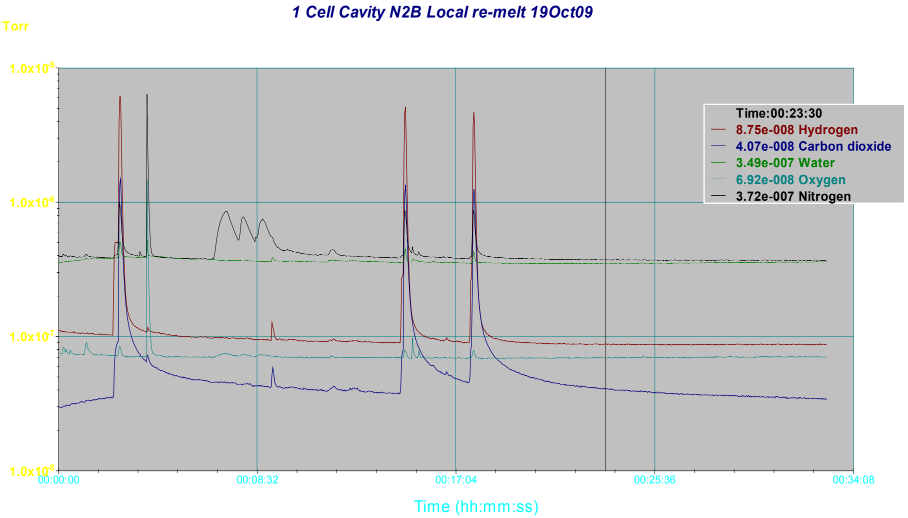
First 9-cell cavity result is poor.

Optimization is being pursued at Fermilab

Electron beam re-melting

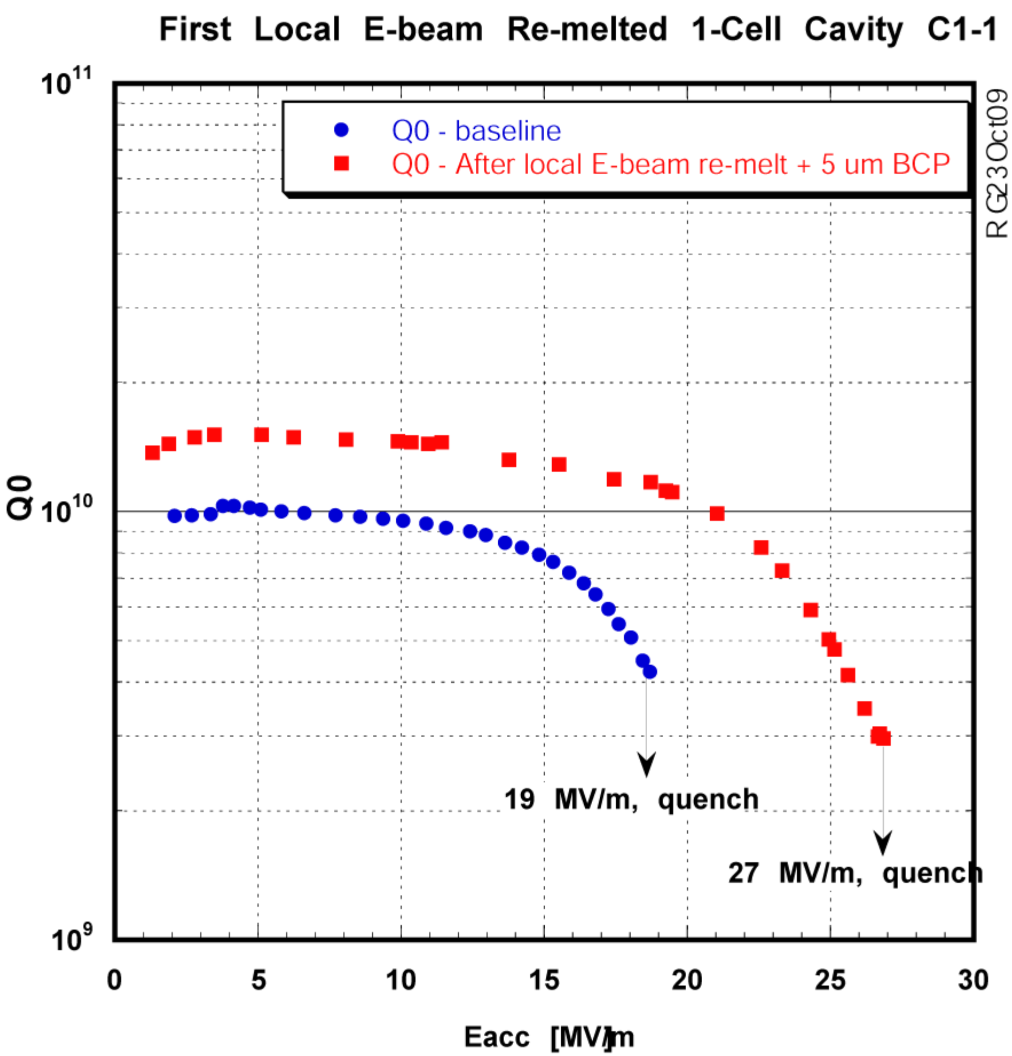
Local electron-beam re-melting smoothed out man-made pits (~200 μm in diameter) in the central surface region of a niobium sample. Pits are visible in the left area (without re-melting) and are completely eliminated in the right area (with re-melting).





3 Doses of spot irradiation which is visible from Residual Gas Analyzer plot

Courtesy of R. Geng of Jefferson Lab

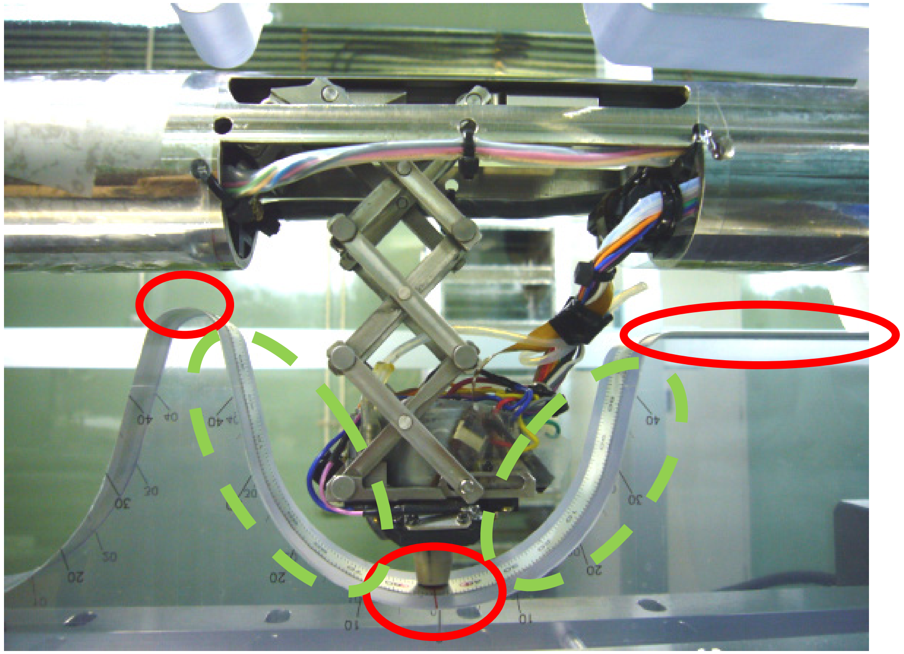


Following the local electron-beam re-melting treatment, the cavity C1-1 was BCP etched for 5 μm removal from the inner surface and HPR rinsed and RF tested at 2 K. Fig. 4 gives the test result before and after the treatment. The quench limit is improved to 27 MV/m from 19 MV/m and the quench location is unrelated to the previous one before the local electron-beam re-melting treatment.

Courtesy of R. Geng of Jefferson Lab

Local mechanical grinding

Grinder #1



To grind at a plane parallel to the beam axis.

- Equator and Outside weld area on the equator
- Top of the Iris
- Beam tube   etc..

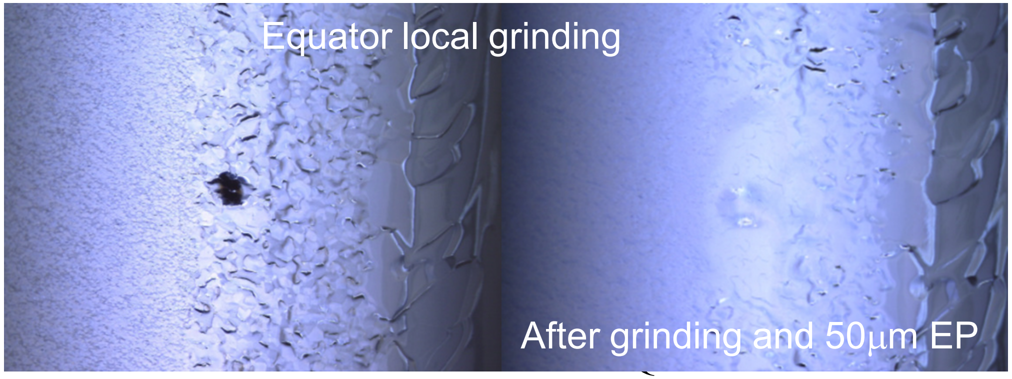
Grinder #3

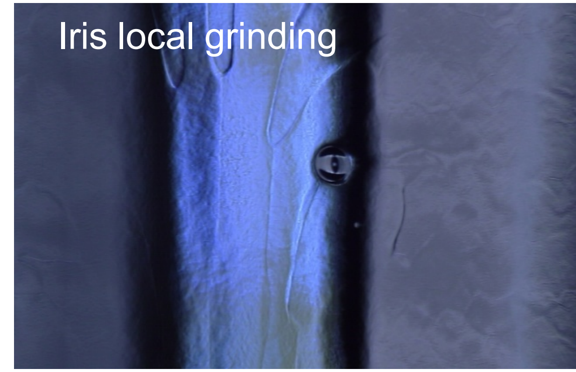
To grind at the reverse side of stiffner ring and the slant face etc..

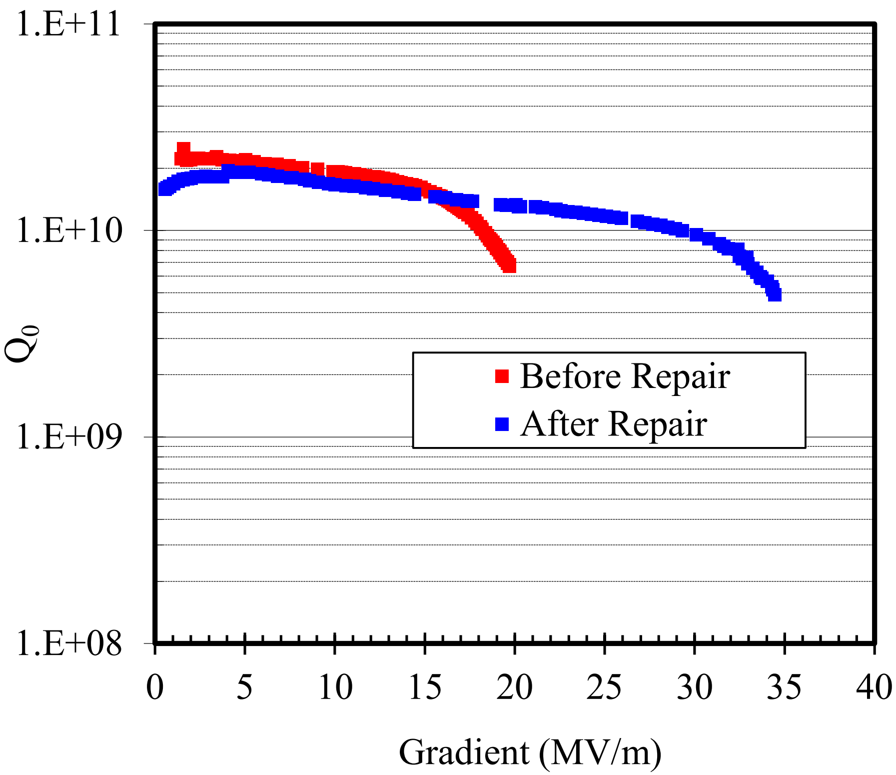
- Iris
- Taper locations

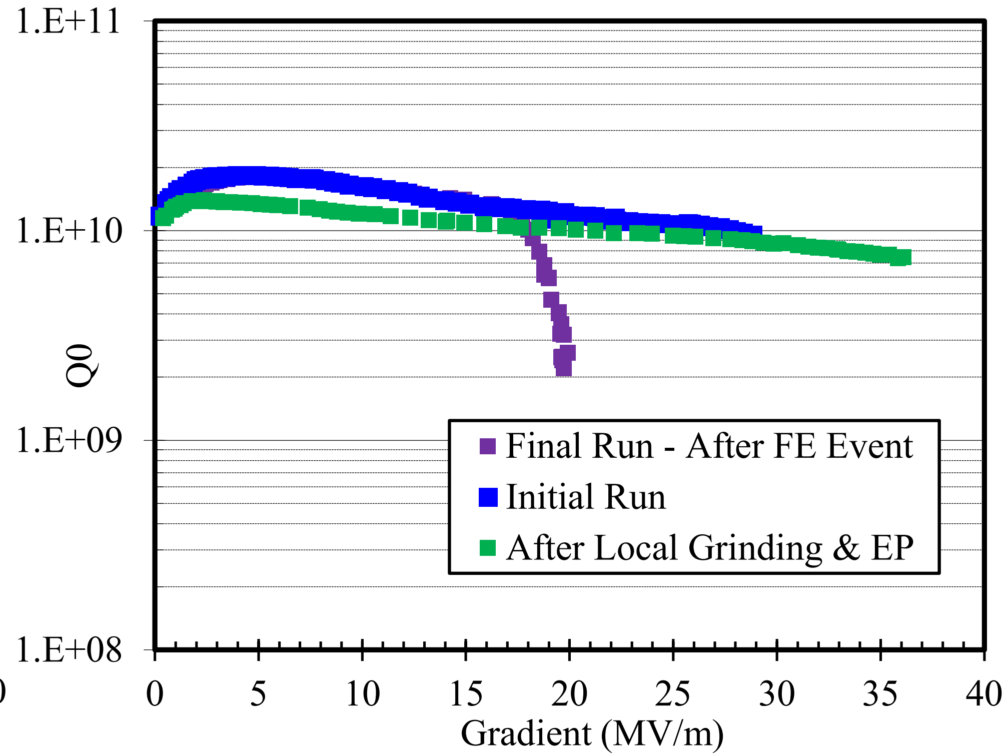
Courtesy of K. Watanabe of KEK

Local mechanical grinding









Courtesy of J. Ozelis and K. Watanabe of KEK

Comparison of guided repair techniques

Process	Laser	E-beam	Grinding	Note
Inert gas purging	Yes			
Vacuum		Yes		Maybe beneficial for laser
Water			Yes	
Light etching	Maybe	Yes	Yes	
Heavy etching			Yes	Depends on damaged layer

Defects	Laser	E-beam	Grinding
Invisible defects			Best
Geometric	Best	Best	
Defect size	<2mm	unlimited	unlimited
Deep defects	Best	Best	
Material			Best
Geometric and material		Better	Best
Risk of expose deep defects	Low	Low	Possible

Conclusions

- Guided repair has potential to be highly efficient and effective to improve SRF cavity performance.
- Various techniques have their own strength and limitations.
- Further improvement is needed for guided repair to reliably operate in production.

Acknowledgements

- M. Ge, Cornell University
- E. Toropov, A. Dzyuba, J. Ozelis, Fermilab
- R. Geng, JLAB
- K. Watanabe, KEK