Requirements for a Next-Generation Cavity Preparation Infrastructure

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Abstract

Several projects like LEP, CEBAF, SNS, and TTF have accumulated experience in the fabrication and preparation of multi-cell superconducting cavities. As there are new projects on the horizon (e.g. XFEL, ILC) it is worthwhile to discuss what are the lessons learned from the existing projects. Following an assessment of the existing experience, the question to be asked could be:
'What are the requirements for a next generation large-scale cavity preparation infrastructure?'

In a first iteration, a list of those requirements has been developed at a TESLA Technology Collaboration Meeting in the beginning of 2005. This document includes 2 parts:

- A summary report on the work on the work group level

- A preliminary list of requirements for a new superconducting cavity preparation infrastructure

The next step is to further refine each individual treatment. A potential layout for a generic infrastructure will be developed.

Part A

Summary talk

Summary of Working Group 1

Lutz Lilje / Peter Kneisel

TESLA Technology Collaboration Meeting April 2005

Outline

- (..)
- Outlook
  - As there are new projects on the horizon (e.g. XFEL, ILC) we believe it is worthwhile to discuss what are the lessons learned from the existing projects. Following an assessment of the existing experience, the question to be asked could be:
- Question:
- 'What are the requirements for a next generation large-scale cavity preparation infrastructure?'
  - This question will be difficult to answer in this one meeting, but we believe that the TESLA collaboration with its new mission should be the focal point for a series of discussions.
  - This process should start now and should be followed-up in the next TESLA/SRF meetings.

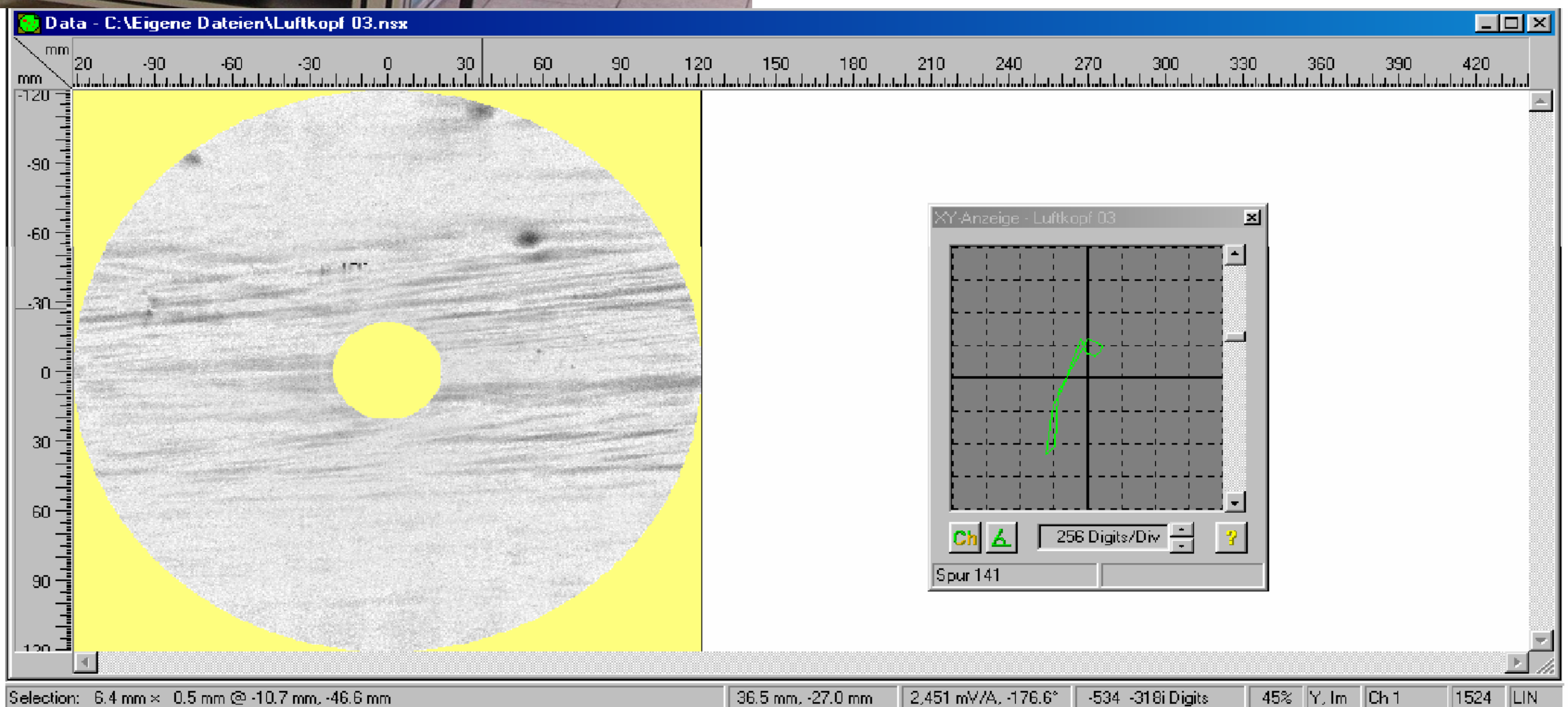
TTF Review

- Eddy-current is consiered to be getting high performance
- Electropolishing + bake is necessary for high performance
  - BCP limits to 30 MV/m
  - Still EP is not yet as reproducible as BCP has been sometimes
- Field emission is a concern and needs work

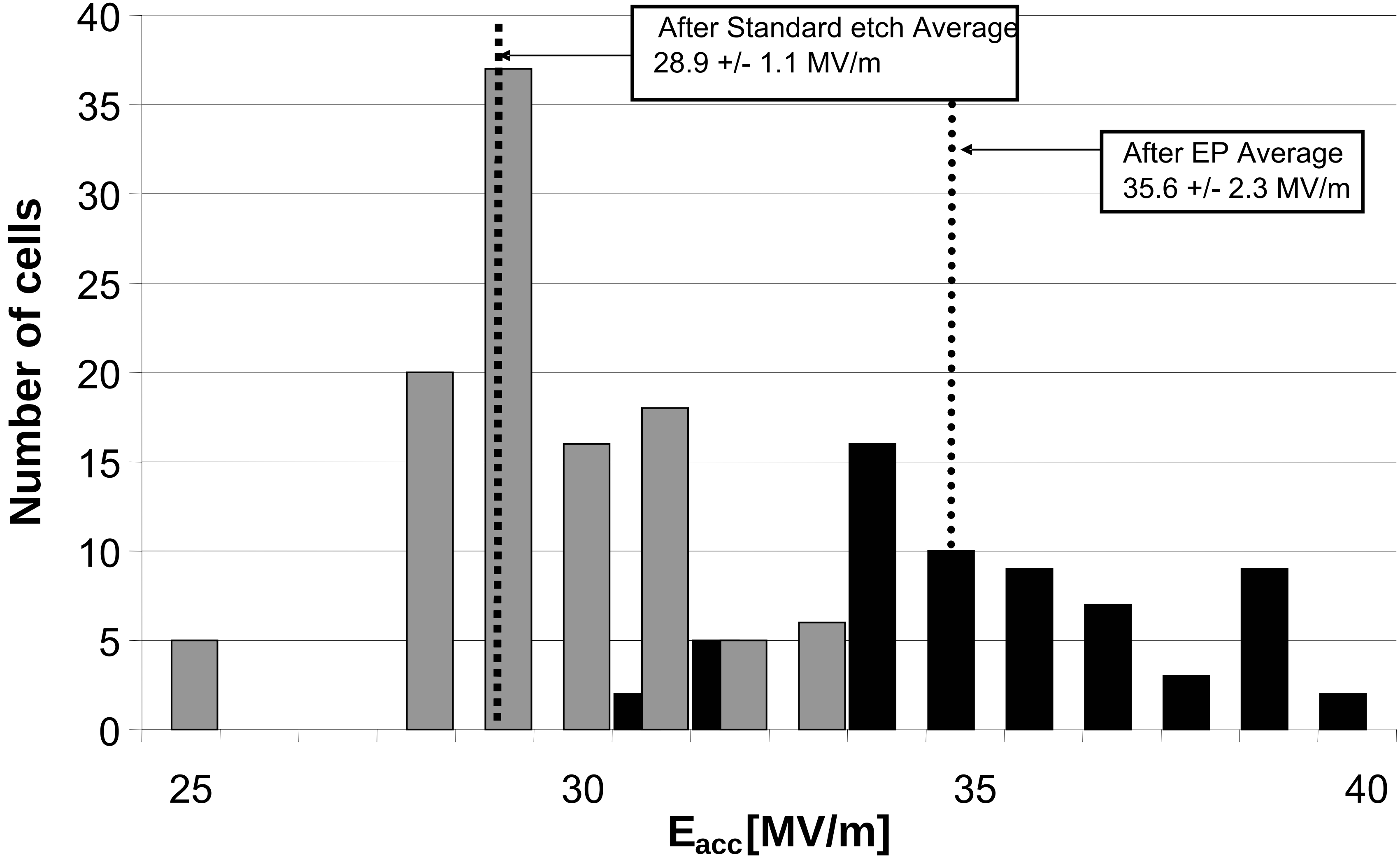
Eddy Current Scanner for Niobium Sheets

Real and imaginary part of conductivity at defect, typical Fe signal

Global view, rolling marks and defect areas can be seen



Comparison of EP to Standard Etch



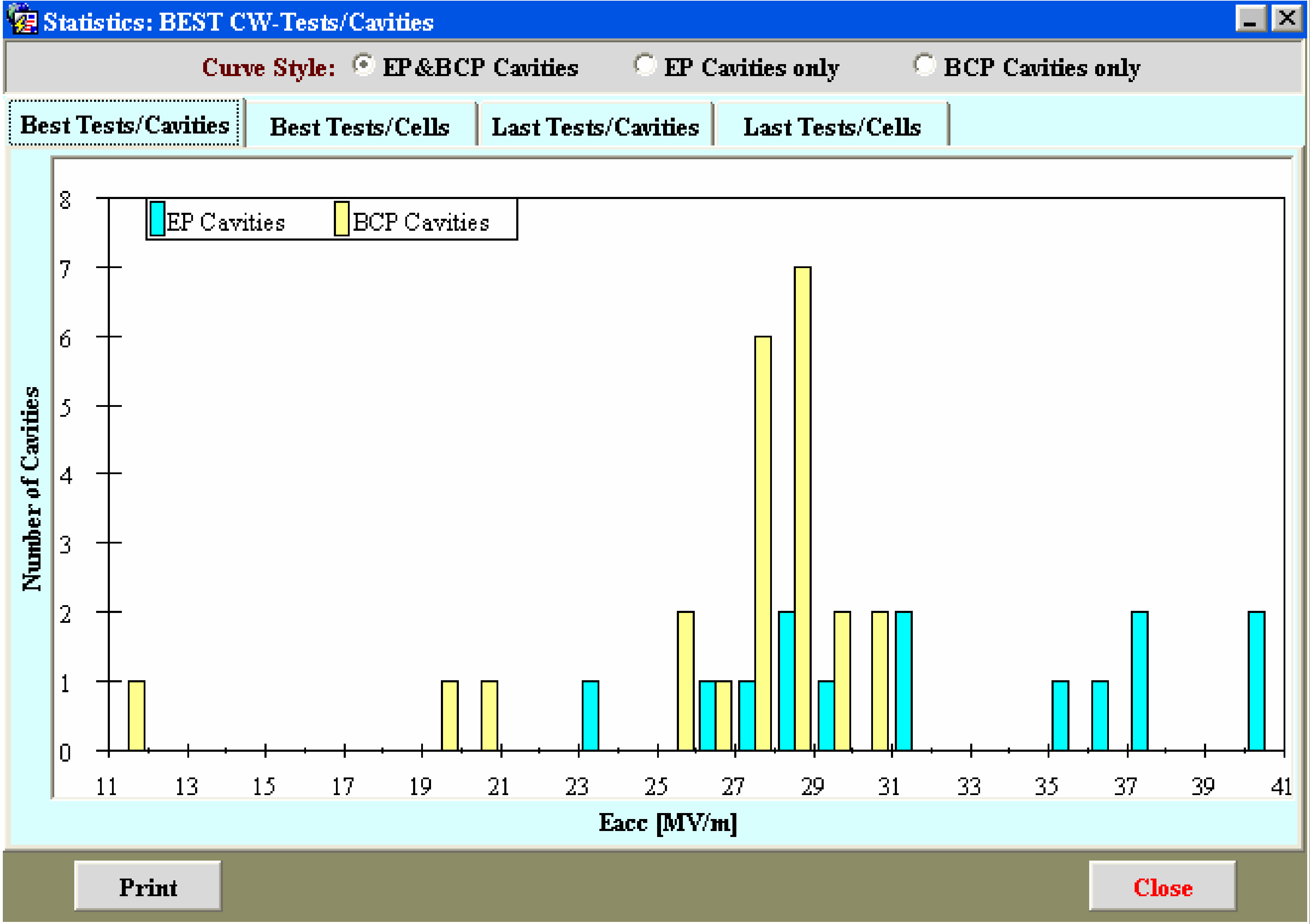
- EP offers systematically higher gradient than standard etch (single cell results from mode analysis of multi-cells)

But:

- Field emission is a major concern

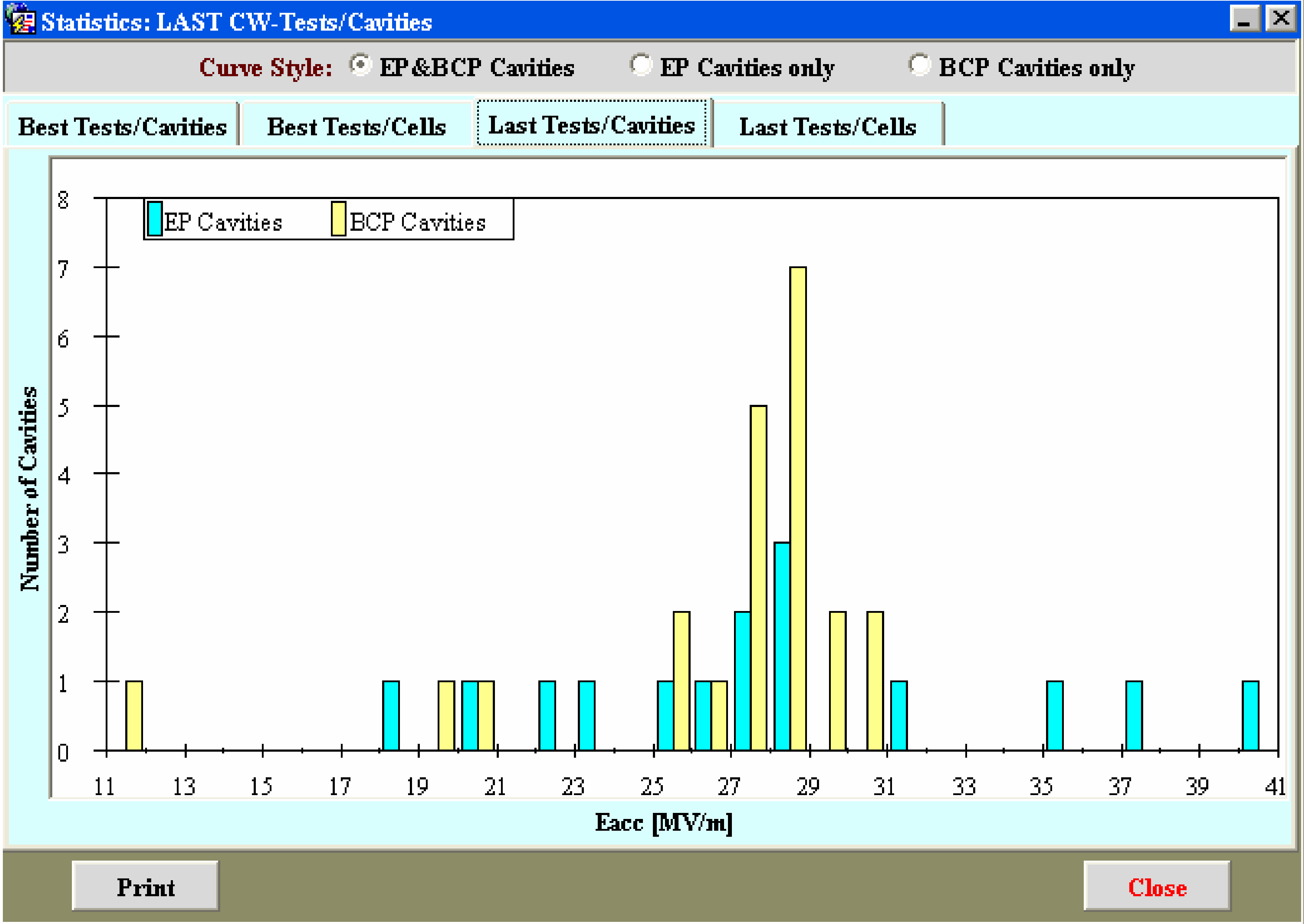
Comparison of best test: EP vs. BCP

- Best test on cavity selected (pi-mode)
- Mixture of 800°C and 1400°C cavities


Statistics: BEST CW-Tests/Cavities
Curve Style:
EP&BCP Cavities
EP Cavities only
BCP Cavities only
Best Tests/Cavities
Best Tests/Cells
Last Tests/Cavities
Last Tests/Cells
EP Cavities
BCP Cavities
Number of Cavities
0
1
2
3
4
5
6
7
8
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
Eacc [MV/m]
Print
Close

Comparison of last test: EP vs. BCP

- Includes new surface preparations due to problems during handling, accidents etc.



Statistics: LAST CW-Tests/Cavities
Curve Style:
EP&BCP Cavities
EP Cavities only
BCP Cavities only
Best Tests/Cavities
Best Tests/Cells
Last Tests/Cavities
Last Tests/Cells
EP Cavities
BCP Cavities
Number of Cavities
0
1
2
3
4
5
6
7
8
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
Eacc [MV/m]
Print
Close

Comments for EP

- Electropolishing delivers higher gradients
  - Potentially can avoid 1400°C treatment
- DESY EP system runs smoothly
  - After start-up problems (sensors, wear on rotary seals, etc)
- A full process is not yet as reproducible as etching (to achieve 35 MV/m)
  - Need for example different way for tank welding to avoid new surface preparation after weld
  - Mainly field emission problems
    - Last year several problems with HPR system

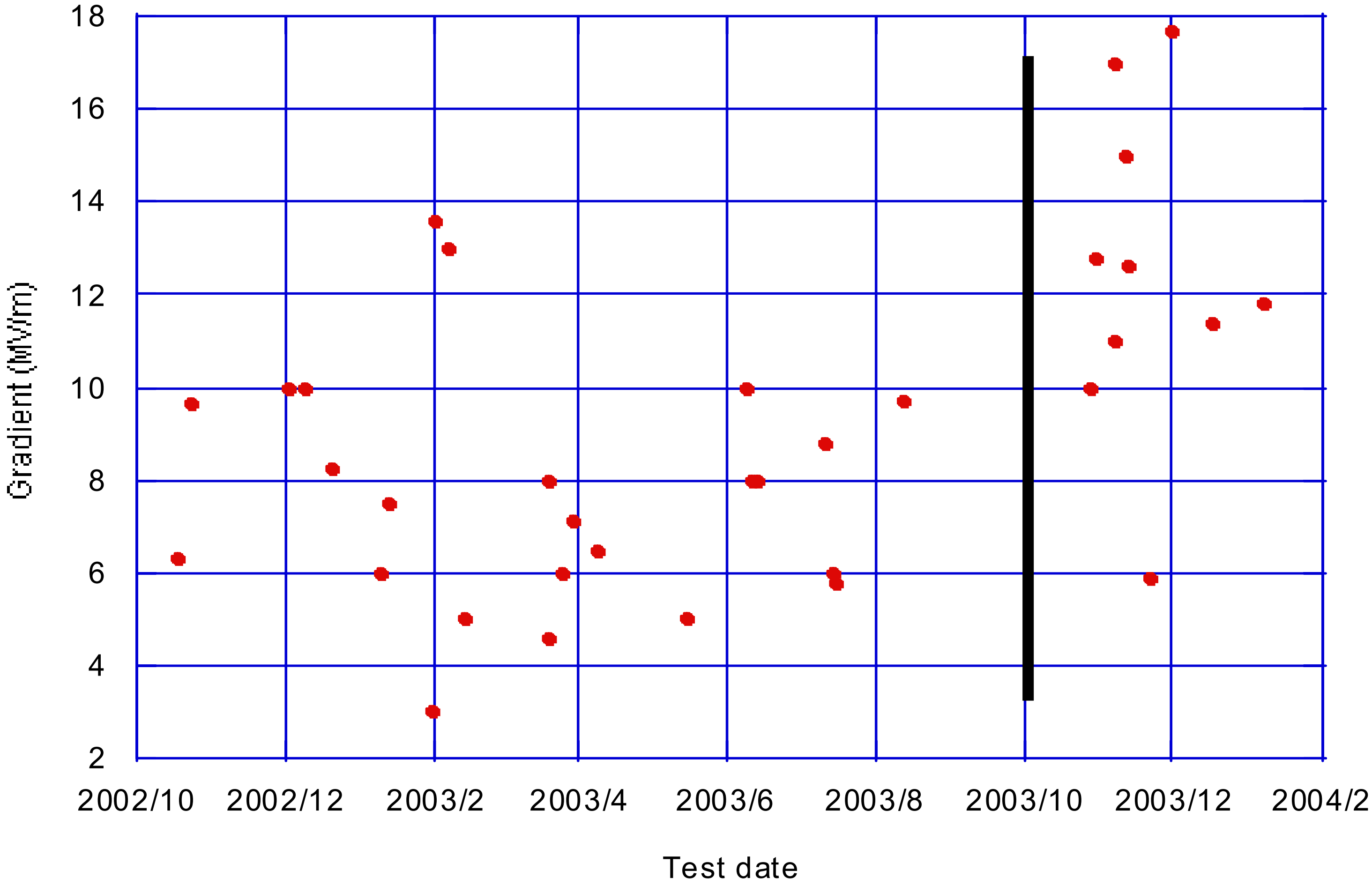
LEP Review

- Production experience with three vendors
- Very important that a CERN Liaison was sent to each company on regular basis
- Company crew should stay with crew from beginning
- Experience of the full process in the lab needed
- Saving on time for testing of components is a bad idea
- Prototyping and learning curve needs to be taken seriously into the scheduling

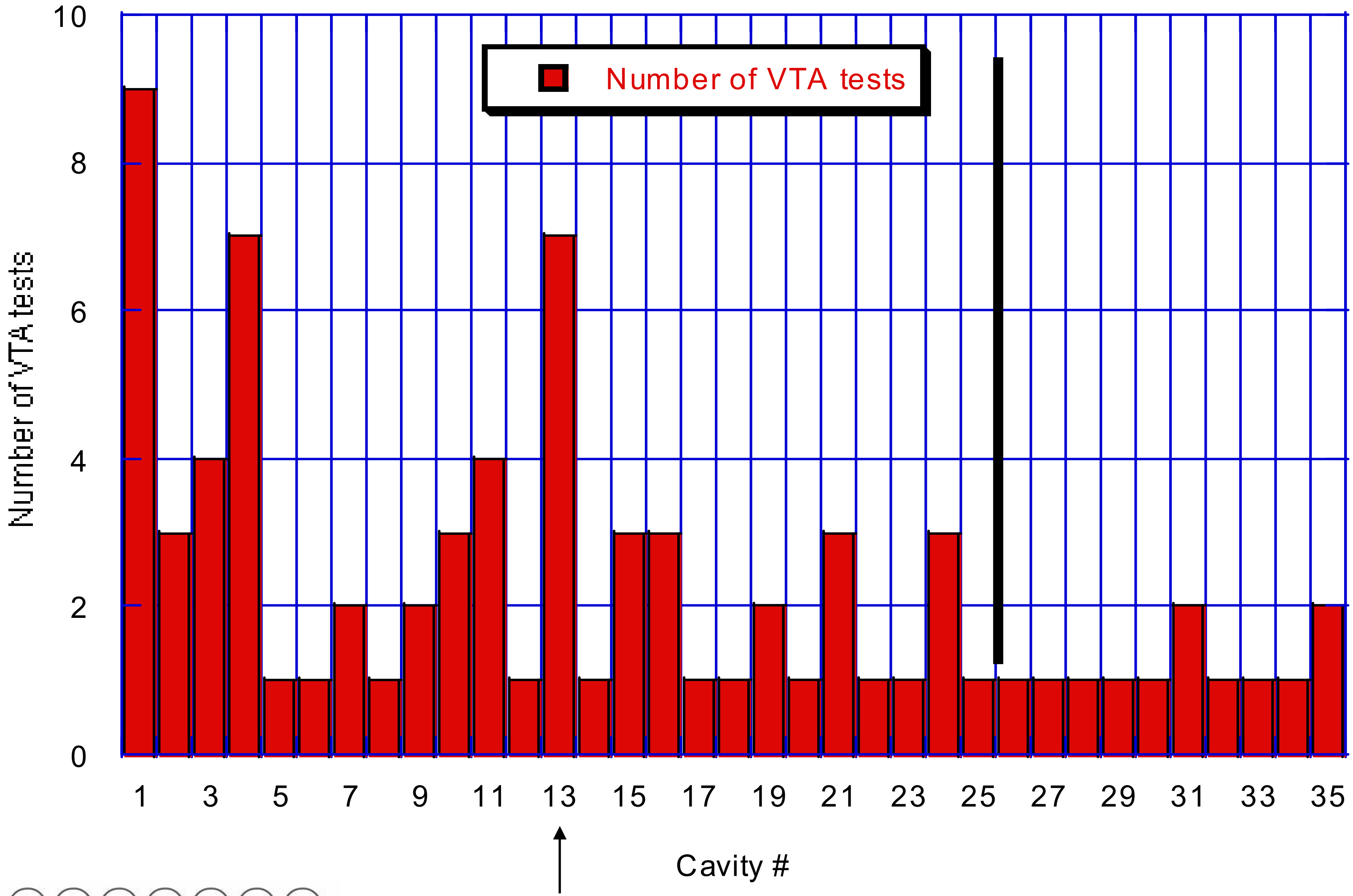
JLab Review

- SNS
  - Major problems with contamination due to inferior HPR system and procedures
  - External review of procedures resulted in modifications and cavity performance improvements
  - Unexpected Multipacting in HB cavities not seen in prototypes
    - However all cavities reached design goals or better
  - Project completed on tight schedule which did not leave room for further improvements
- Cebaf
  - For the upgrade string hot water rinsing after BCP seemed to be beneficial
  - More stringent QA measures have been introduced for string assembly

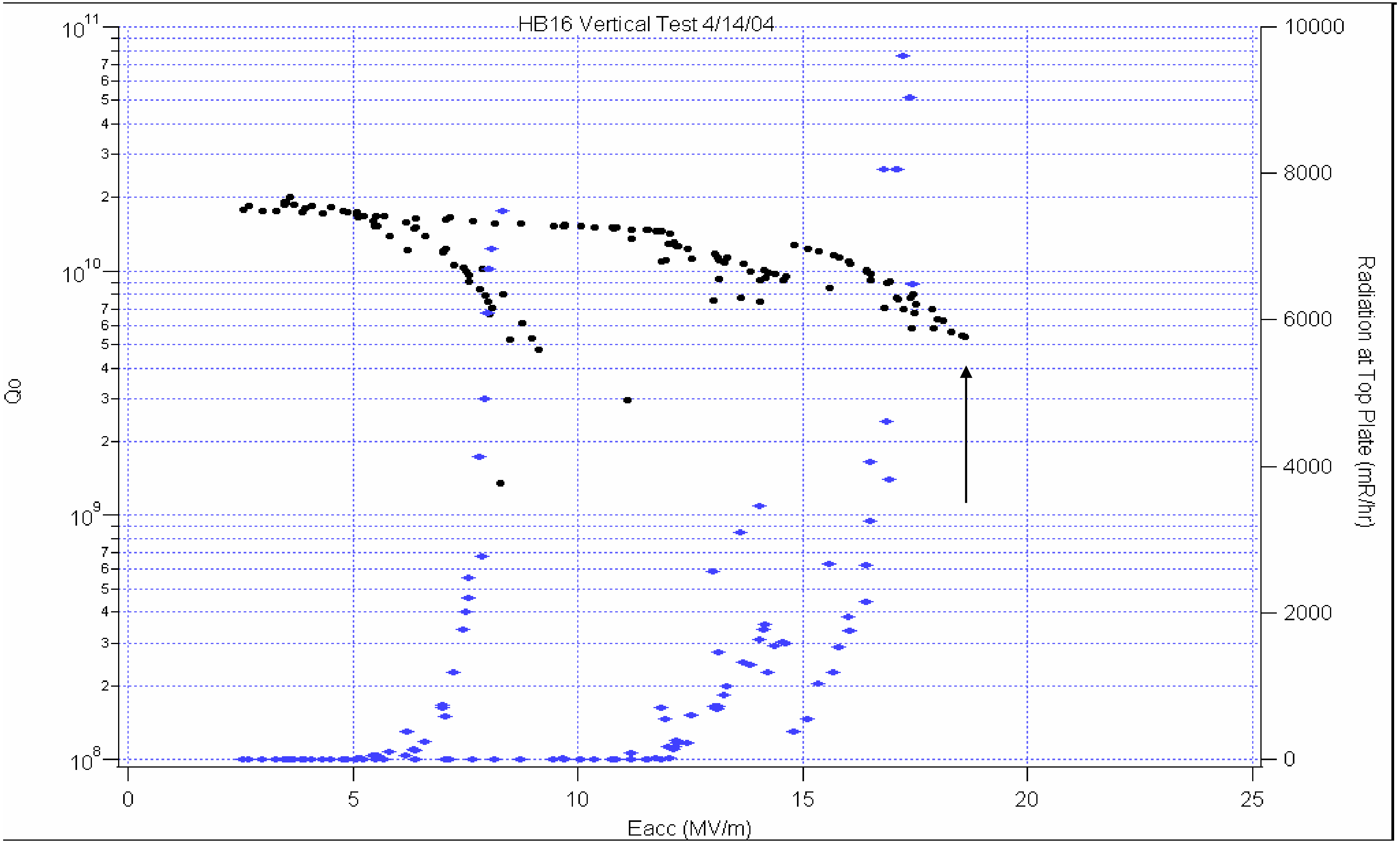
MB FE –onset by VTA Test Date



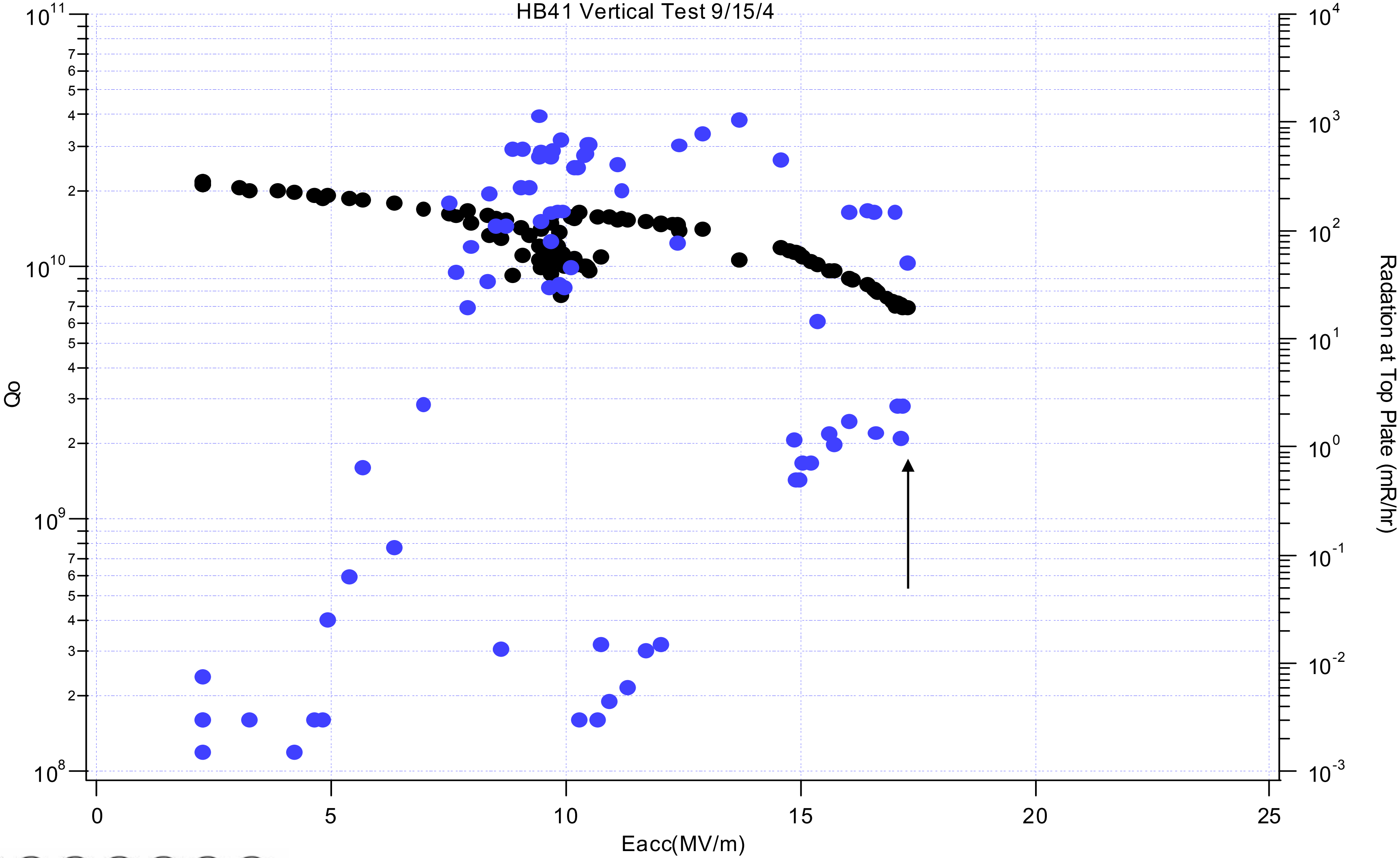
Number of Vertical Tests Performed MB



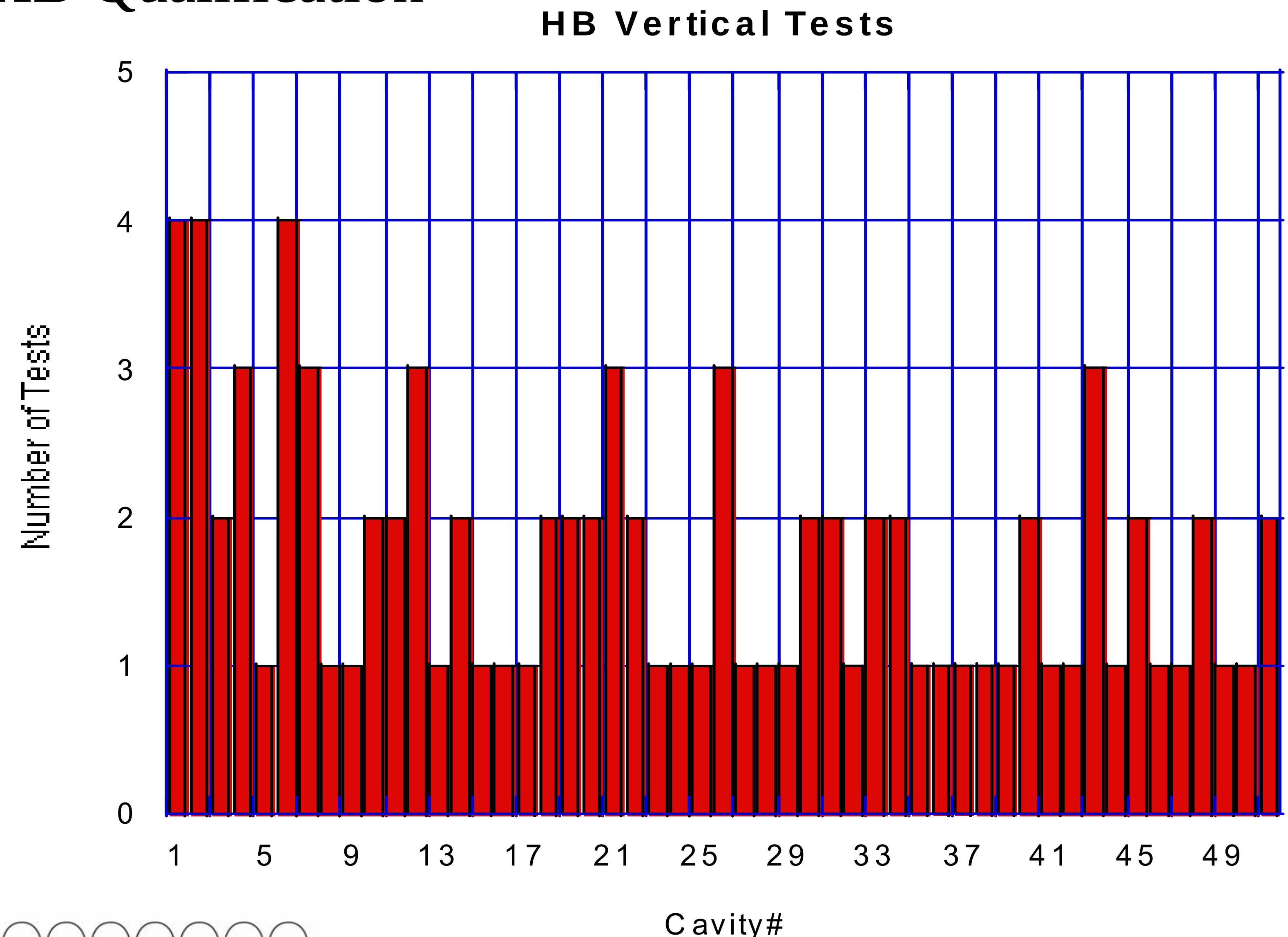
HB Vertical Test Data

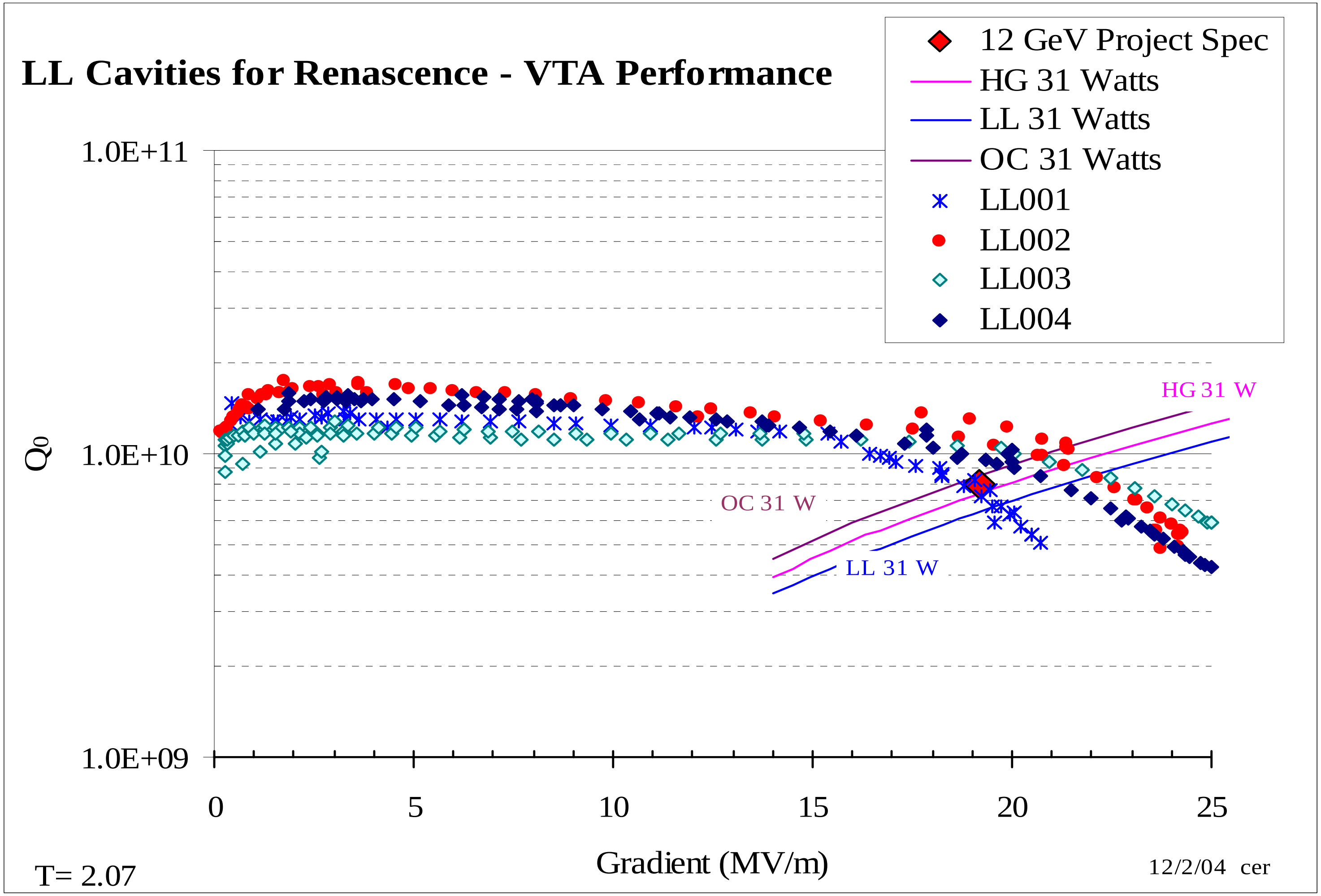


HB Vertical Test Data



HB Qualification





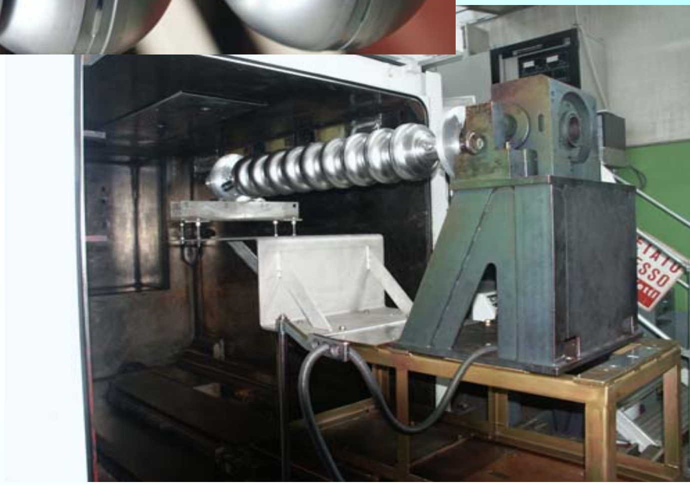
LL Cavities for Renascence - VTA Performance
12 GeV Project Spec
HG 31 Watts
LL 31 Watts
OC 31 Watts
LL001
LL002
LL003
LL004
1.0E+11
1.0E+10
1.0E+09
Q0
HG 31 W
OC 31 W
LL 31 W
0
5
10
15
20
25
Gradient (MV/m)
T= 2.07
12/2/04 cer

SC Cavities

From Prototype to Series Fabrication (W. Singer)

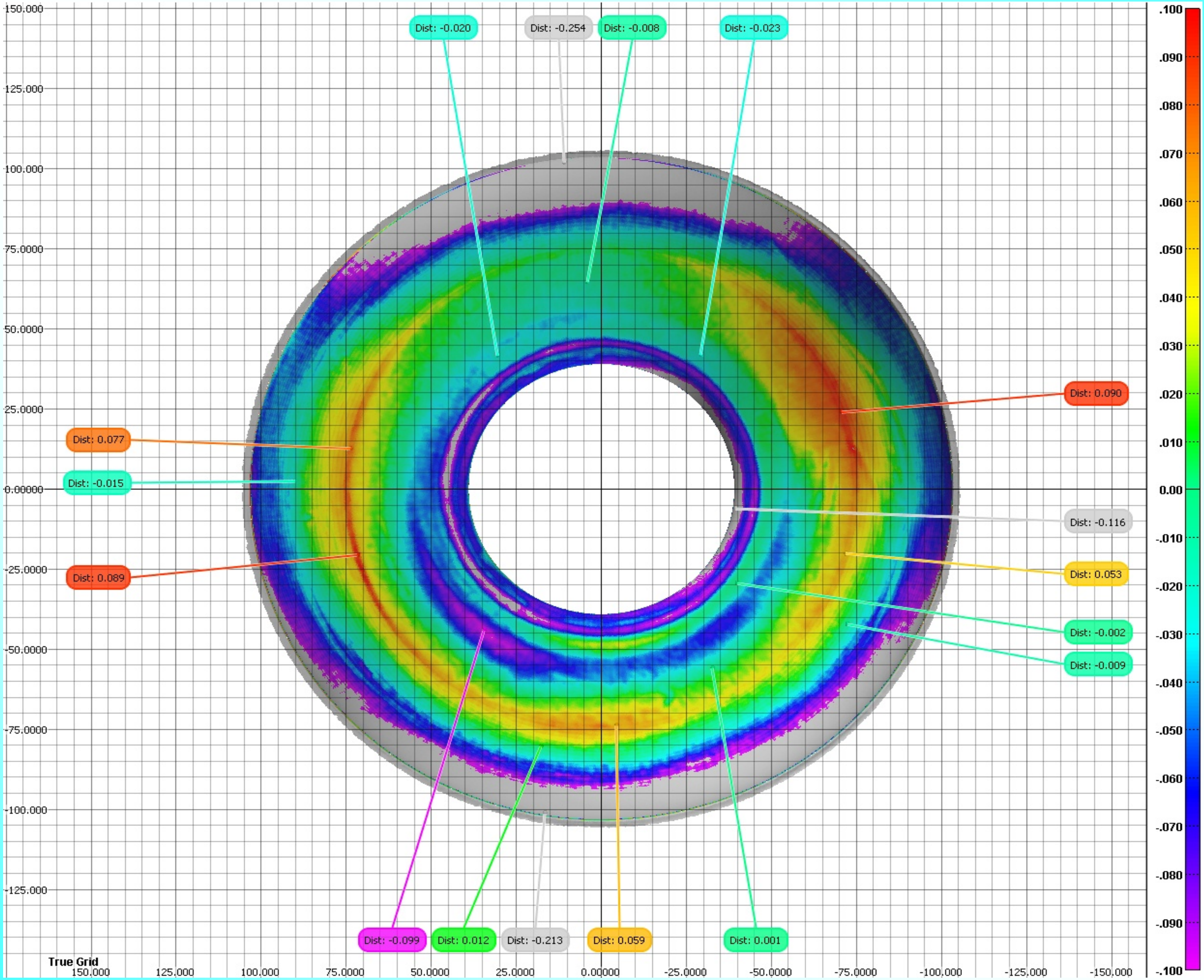
- 4th cavity production series at ZANON
  - The method of welding full cavities has been succesfully tried out
    - Cavity reaches ~33MV/m (Quench, strong FE)
  - First tests with 3d-measurement system for the cell shape
    - Many frequency and trimming steps during fabrication
    - Should be avoided (cost)
  - Documentation of the fabrication via EDMS
- Large grain material ordered

Current fabrication of 30 TTF cavities at ZANON



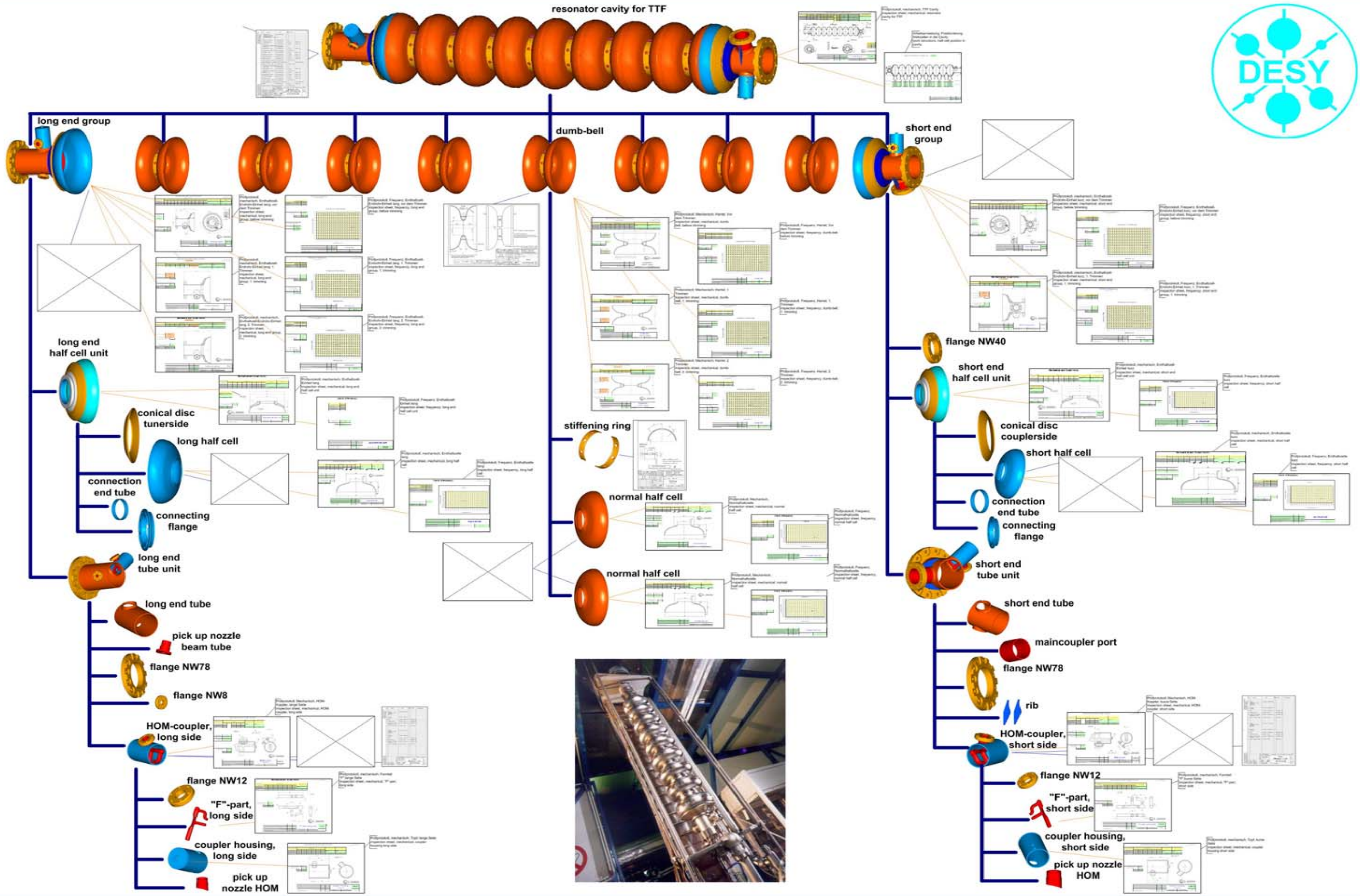
Fabrication procedure

- fabrication of dumb bells and end groups
- assembling of all parts by special tool
- tacking
- disassembling
- completing

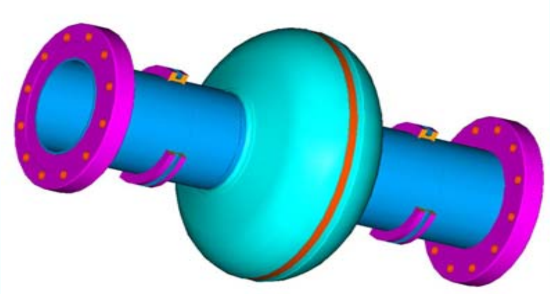


Instead shape correction by trimming improve the shape accuracy

Optical 3D measurement of the deep drawn TTF half cell

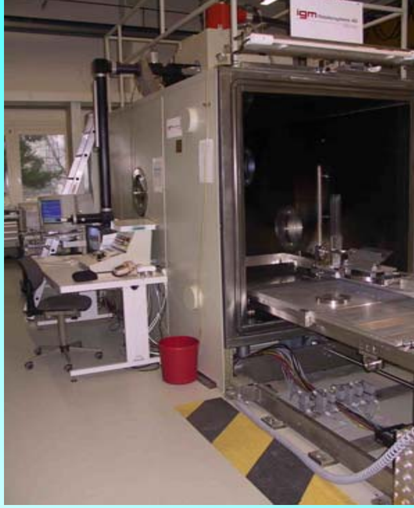


Application of EDMS for cavity fabrication



Single cell cavity R&D at DESY

DESY EB welding device



1. Cavity from ingot with very large grain

2. Qualifying of new Nb suppliers

- Two qualified Nb sheet suppliers: Wah Chang (USA), Tokyo Denkai (Japan).
- HERAEUS (Germany) quit the sheet fabrication. Proposed option. HERAEUS- supply high purity Nb ingots. Fa. Plansee (Austria) - sheet fabrication from Nb ingots. Plansee have to be qualified.
- Several companies anticipate to be qualified. Most of companies installed or overhauled the EB melting facilities: CBMM (Brazil), Cabot (USA), NIN and Ningcha (China)

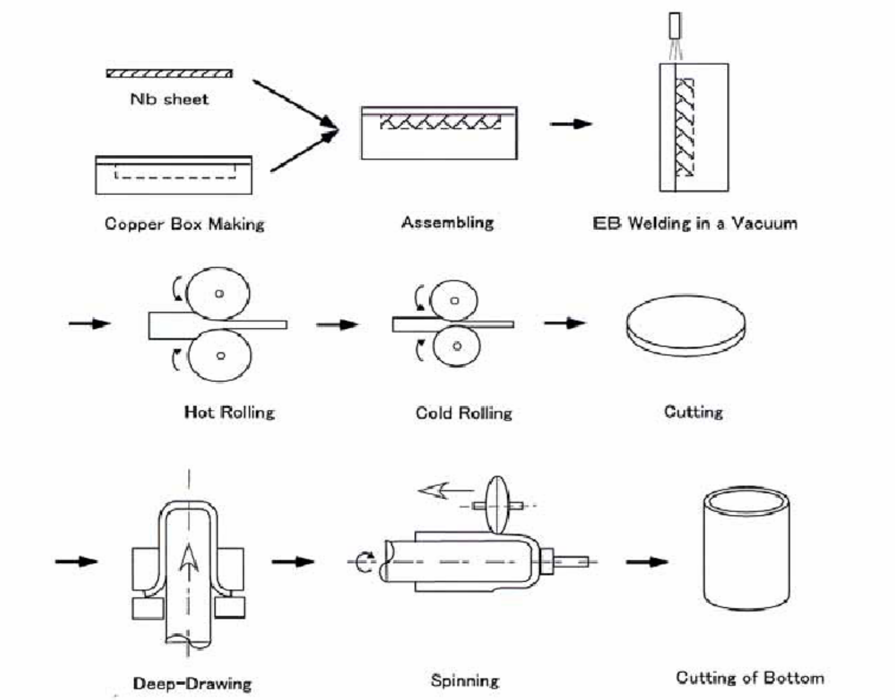
3. Rework the specification for fabrication of 9- cell cavity

- Check the eight hours rule etc.

4. Rework the Nb specification:

- Nb with high thermal conductivity (RRR 700-900)
- Check the Ta content

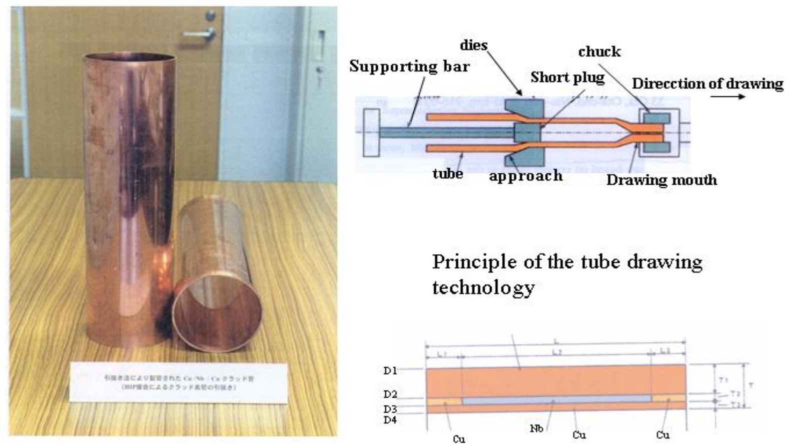
KEK: Fabrication of hot bonded NbCu tubes



Hot roll bonded Cu-Nb-Cu tube
Nippon Steel Co. and KEK

Fabrication principle of sandwiched hot rolled Cu-Nb-Cu tube (KEK and Nippon Steel Co.)

Fabrication principle of sandwiched coextruded Cu-Nb-Cu tube (KEK)



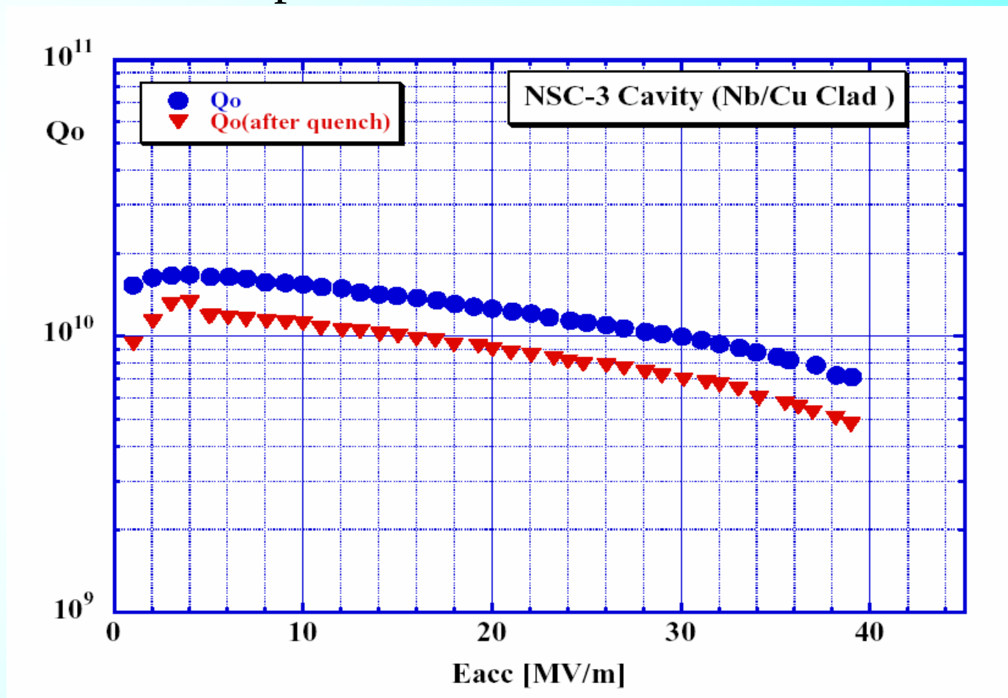
Cu-Nb-Cu Sandwiched Tubes (KEK)

Single cell NbCu cavities produced at DESY by hydroforming from KEK sandwiched tube.

Next step : Fabrication of multicell NbCu clad cavities

One NbCu sandwiched cavity was tested NSC-3.

Hot roll bonded tube fabrication at Nippon Steel Co., hydroforming at DESY, Preparation and RF tests at KEK



NSC-3: Barrel polishing, CP(10microns), Annealing 750°C x 3h, EP(70microns) by K.Saito

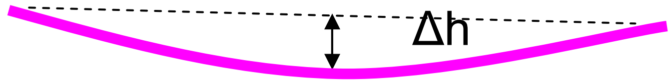
R&D on Samples in Wuppertal

- Arti Dangwal
  - DC field emission scanning
    - » Improved automated setup
    - » First tests on EP samples
- Günter Müller
  - Micro Profilometer with AFM
    - » Surface conture measurements up to 400 cm2 size and 50 mm height
    - » Non-destructive surface shape control of electropolished Nb samples
    - » Roughness measurements of flat and curved Nb surfaces (CP, EP)
    - » Zooming scales over 8 orders of magnitude (from dm to nm)
    - » Fast detection of particulate contaminations (> µm) on Nb samples

Results on Nb Samples:

- 2 EP-Nb samples from DESY (# 10, #11)
  - Surface observed NOT FLAT
  - CONCAVE CURVATURE

    (Δh > 100 μm, 70 μm)
  - Scanning at fixed distance Δz < 100 μm is not possible yet



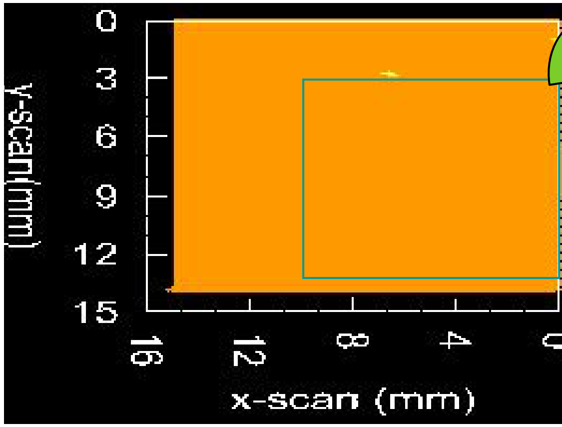
- Probable causes
  - Inhomogeneous electric field distribution during EP
  - Mechanical pressure on sample in FM coupler port

⇒ Modification of sample position during EP is required!

Regulated V-scans on EP-Nb sample from Saclay (SEP1)

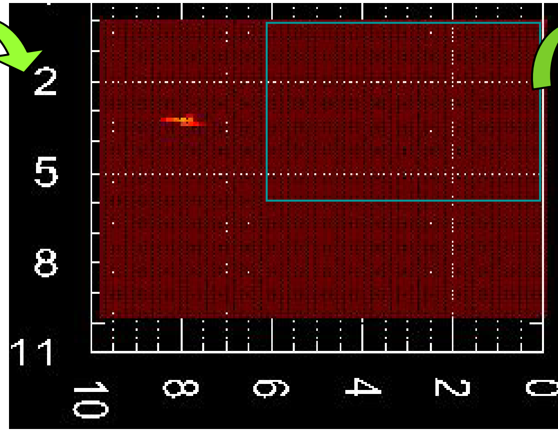
Anode diameter = 300µm, Δz = 50 µm (±5µm)

E= 60MV/m



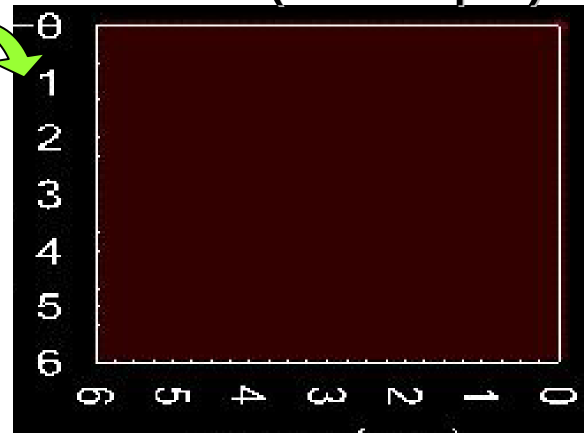
N ~ 1emitter/cm²

E= 90MV/m



N > 1 emitter/cm²

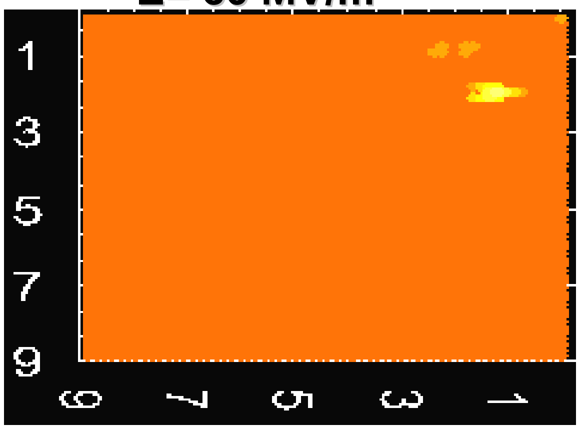
E= 120MV/m (4.8kV/40µm)



No emission in selected area!

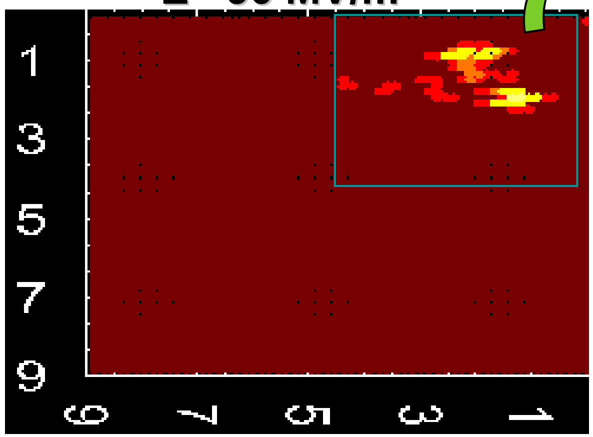
⇒ EP is effective up to E=120MV/m

E= 60 MV/m



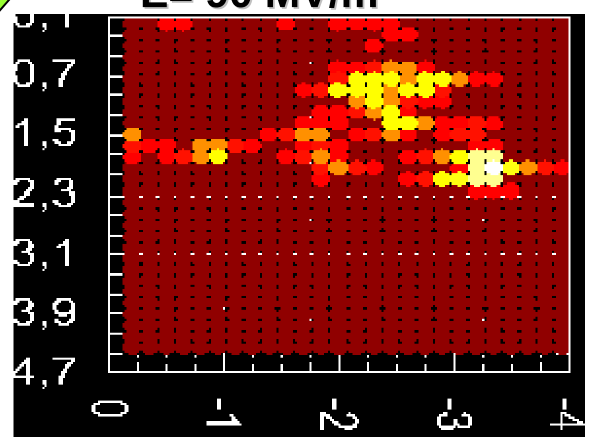
N ~ 5 emitters/cm²

E= 90 MV/m



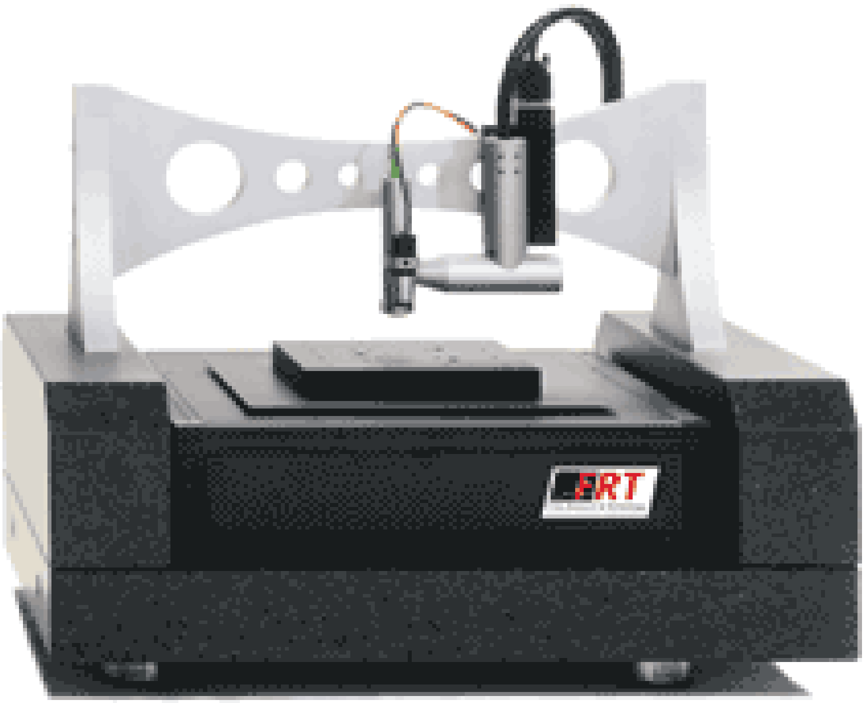
N ~ 11 emitters/cm²

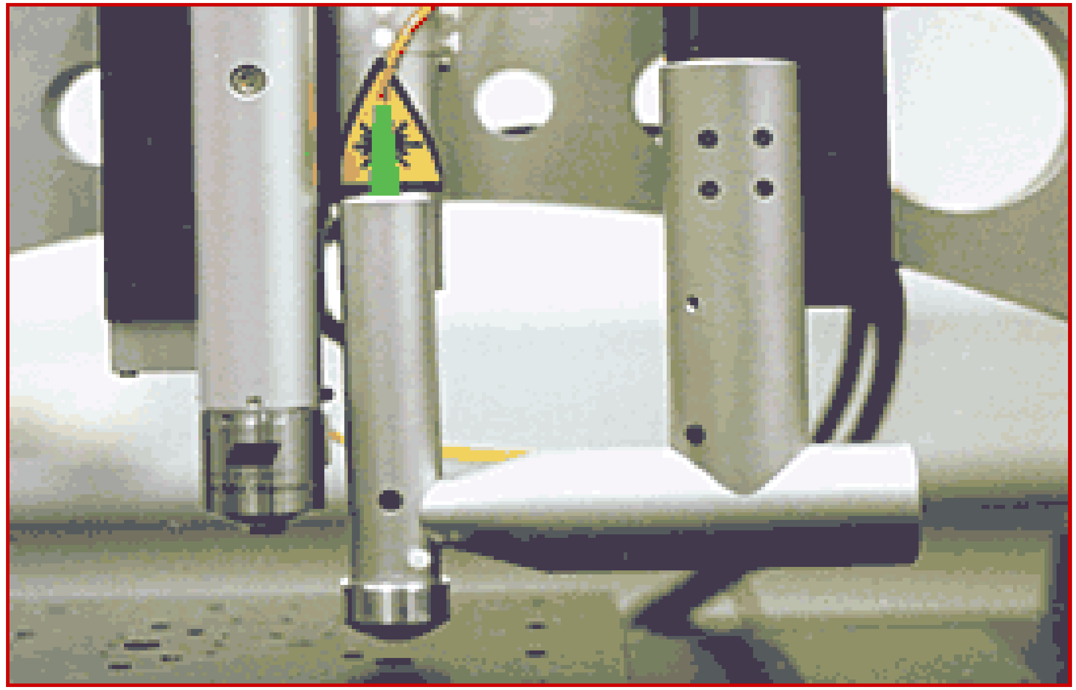
E= 90 MV/m



N ~ 13 emitters/cm² ⇒ 70/cm²

FRT Micro Profilometer with AFM





Chromatic abberation sensor:

Scanning area up to 200 x 200 mm^2

Scanning speed: 100 mm/s

Measurement distance: 4.5 mm

Lateral resolution: 1 - 2 µm

Height resolution in 300 µm range: 3 nm

Atomic force microscope AFM:

Selected scanning area < 80 x 80 μm^2

Scanning speed: 1-5 lines/s

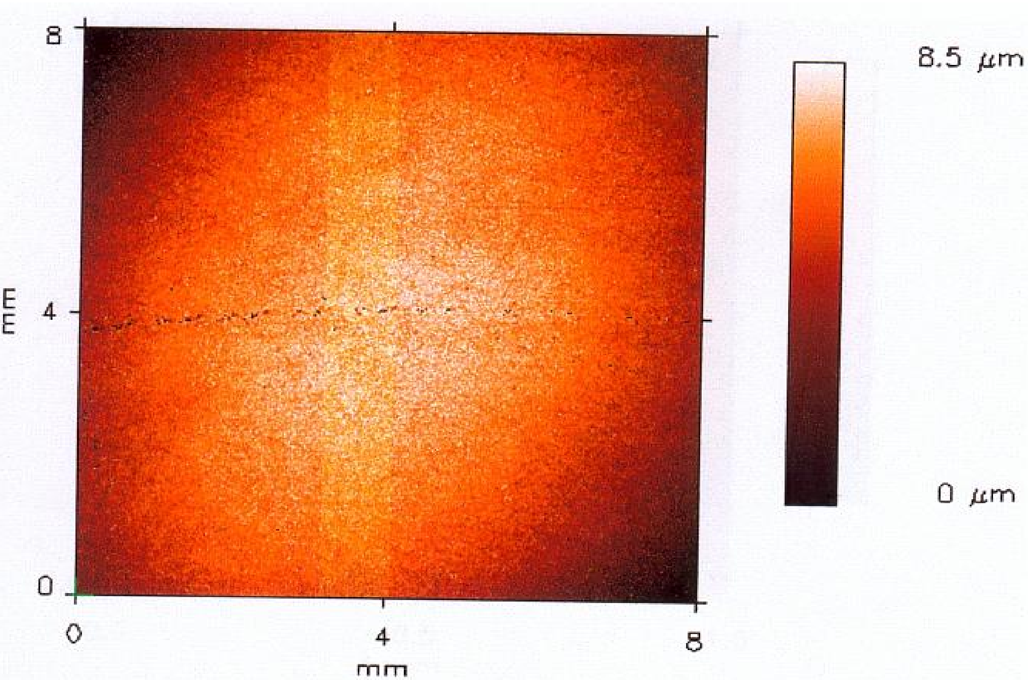
Lateral resolution: typ. 5 nm

Height resolution in 6 µm range: 1-2 nm

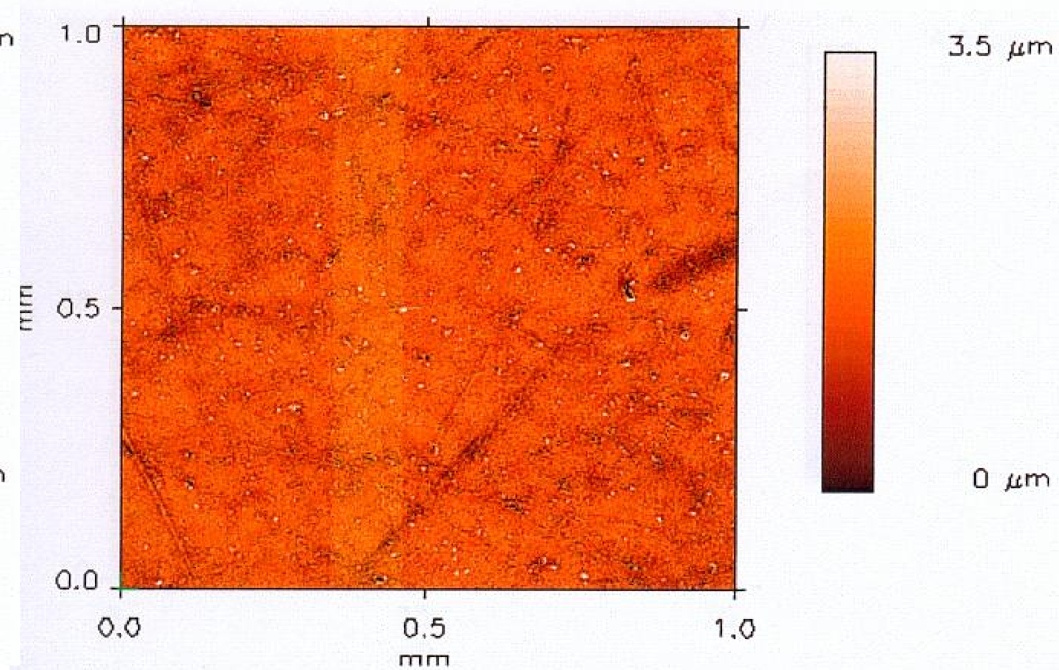
Electrostatic and magnetic force modes

Exemplaric results on electropolished Nb sample

Chromatic sensor image of the sample



Detail image of area 1 x 1 mm^2



Convex curvature of surface obvious

~ 8.5 µm over 8 x 8 mm^2

Hole trace follows original scratch

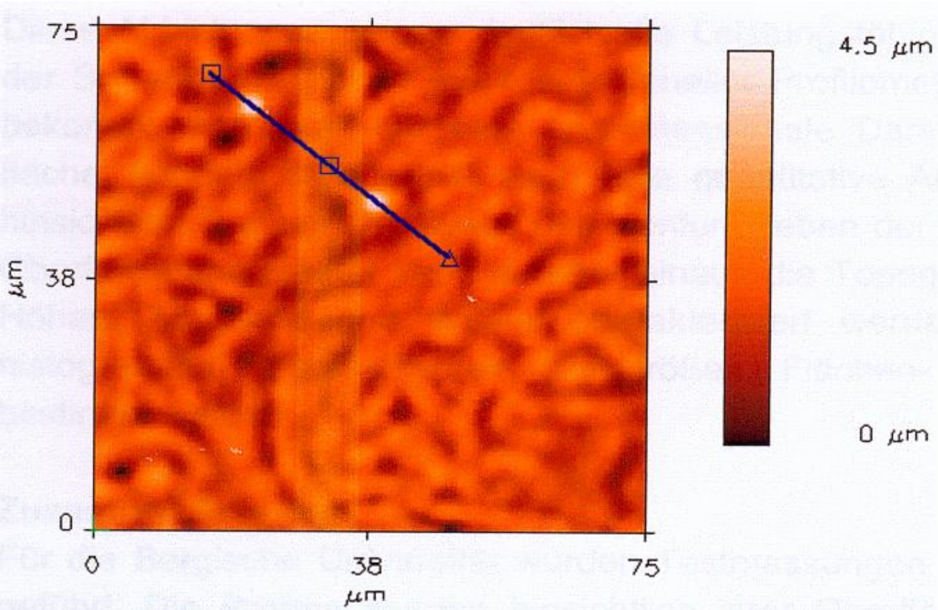
Typical Surface roughness of some µm

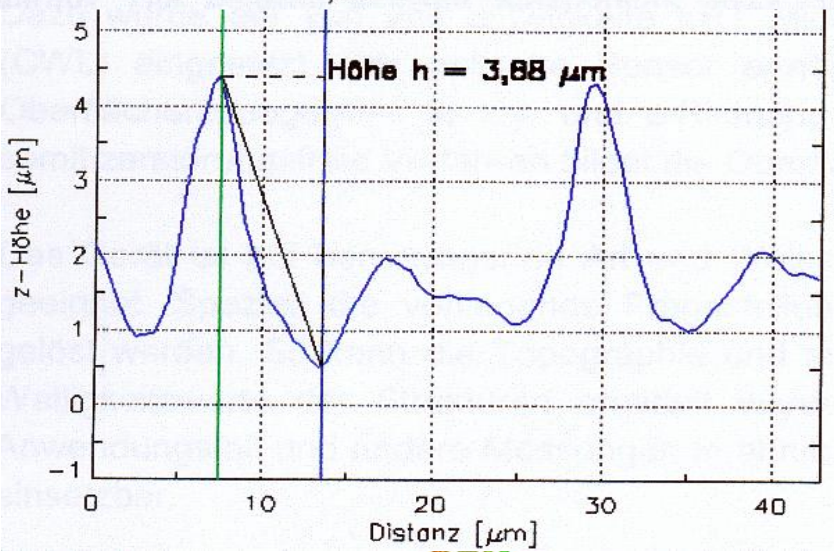
due to ditches of 100 - 500 µm length

Contamination with microsized particles

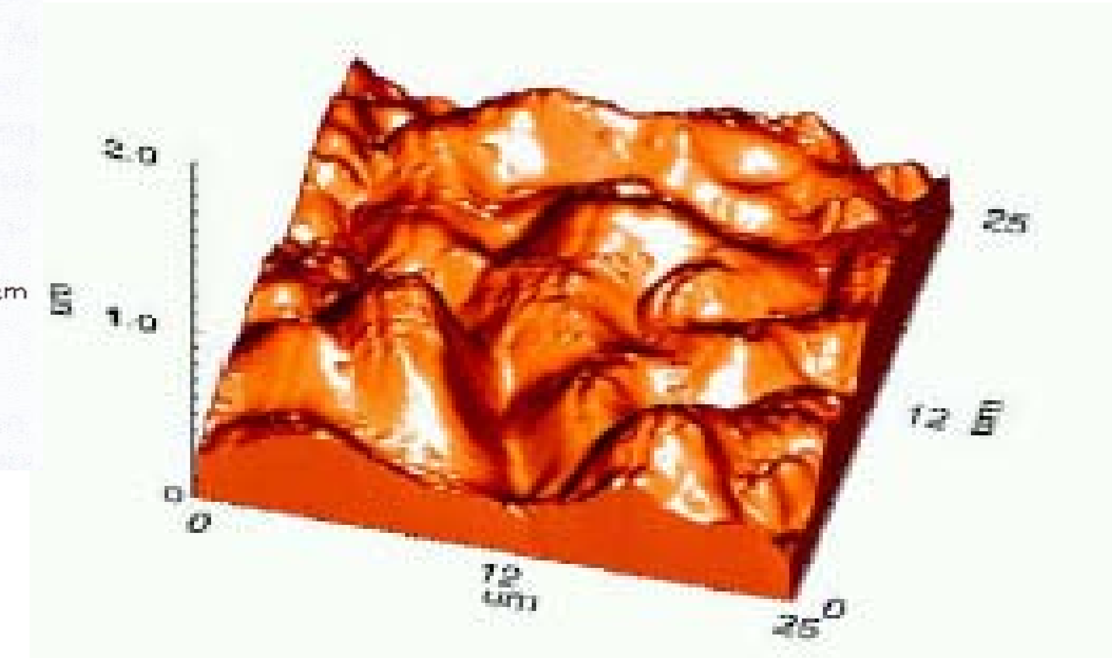
Exemplaric results on electropolished Nb sample ctnd.

Chromatic sensor image of 75 x 75 µm²





AFM image of typical area 25 x 25 µm²



Local surface roughness ~ 0.5 µm

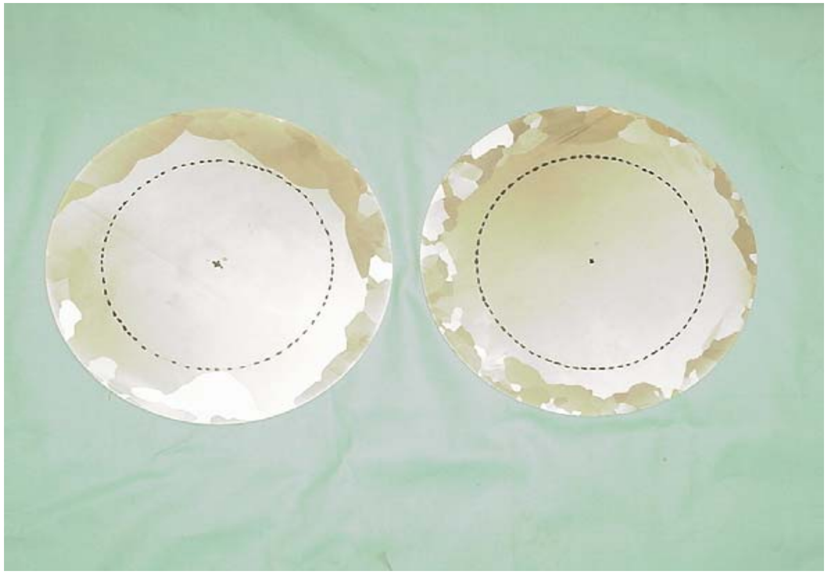
Many nanosized particles on surface

R&D at Jlab

- Q-drop
  - What is it?
- This basic research activity led to some new development in the niobium material technology
  - Single crystal/ Large grain material tried out to understand whether Q-drop relates to grain boundaries
  - This technology might have some cost advantages (will also be tried in XFEL R&D program)

Single Crystal Niobium Cavity (1)

Discs from Ingot



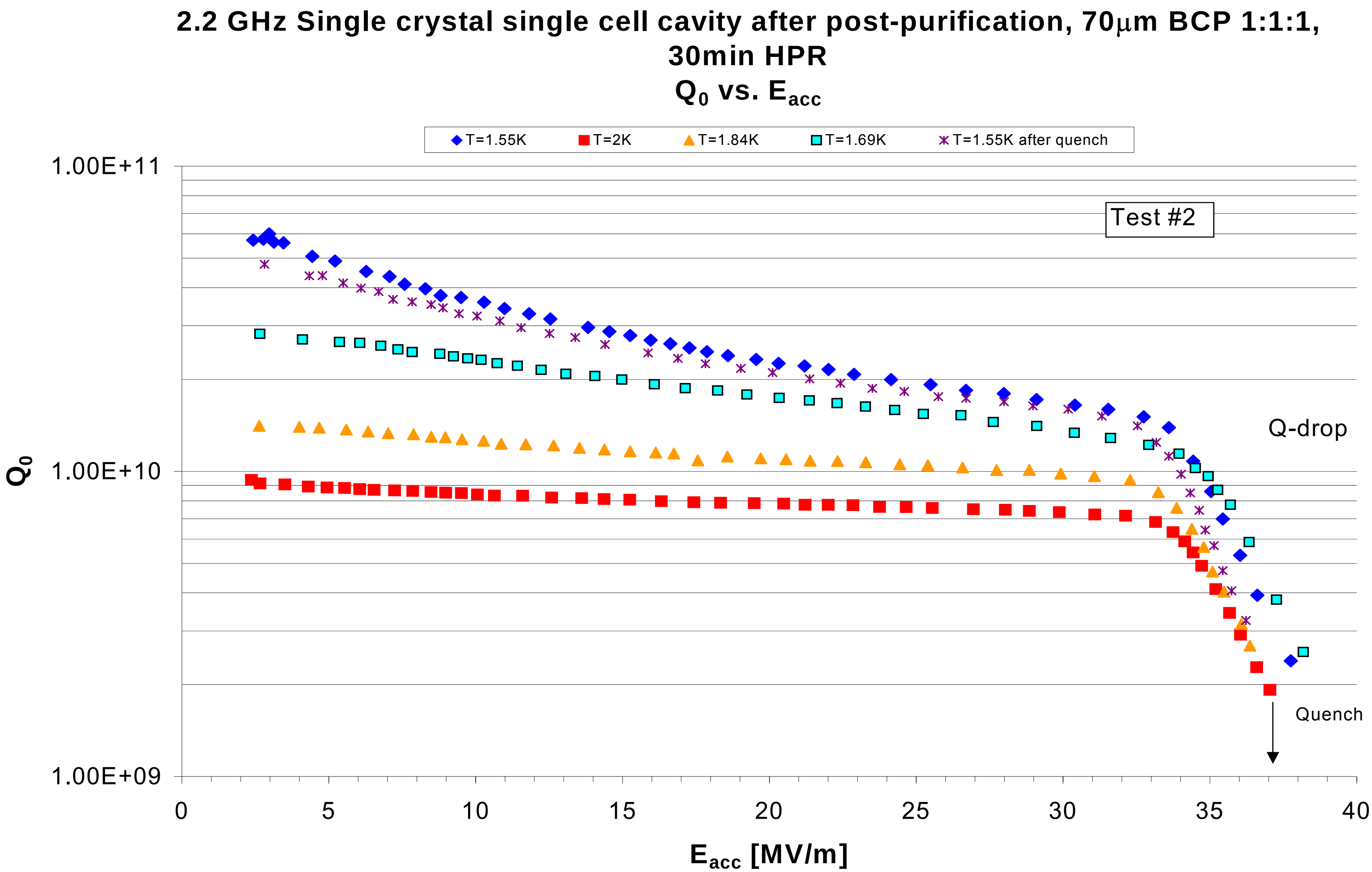
Cavity

$E_{peak}/E_{acc} = 1.674$

$H_{peak}/E_{acc} = 4.286$ mT/MV/m

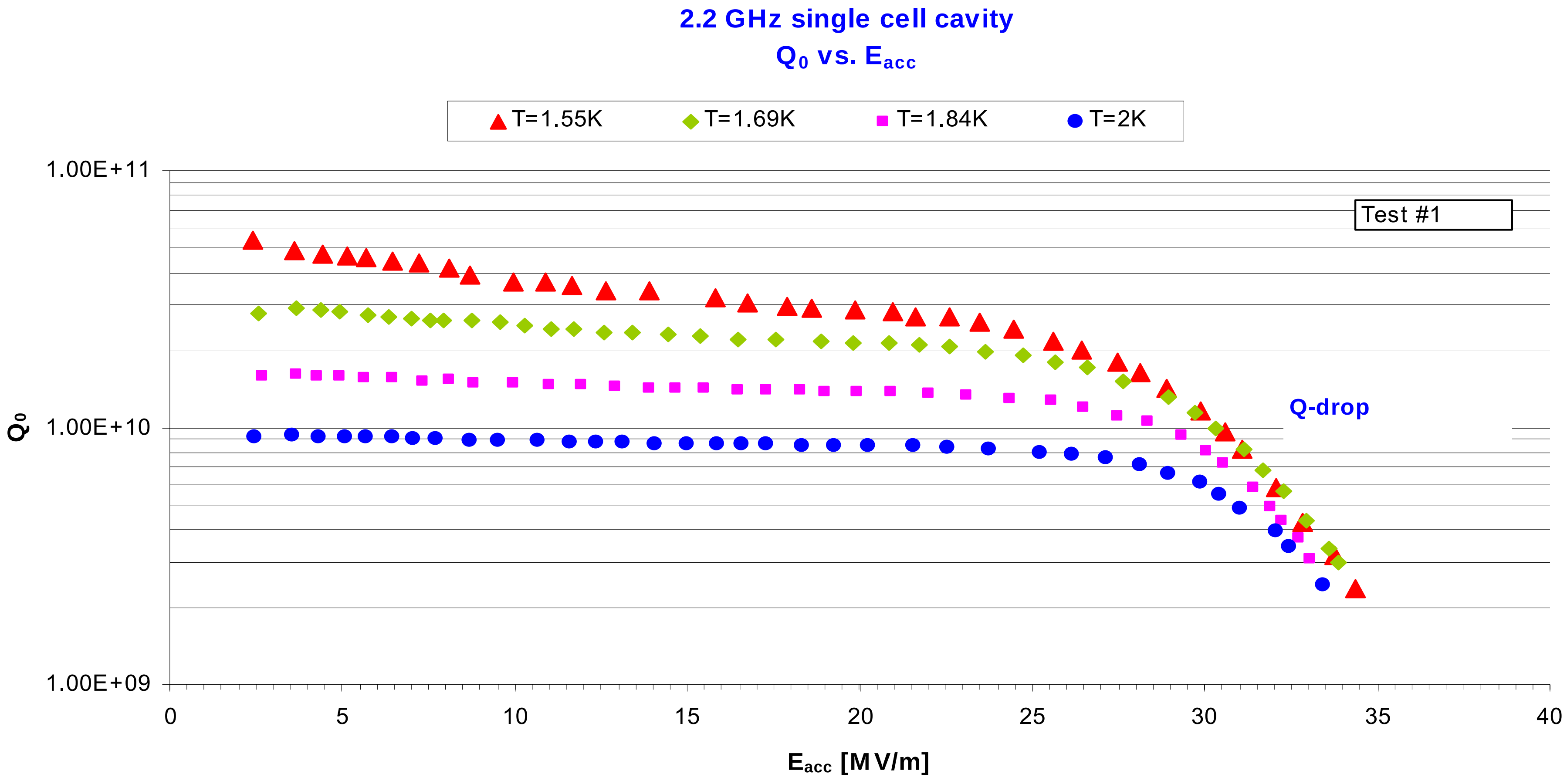
Single Crystal Niobium Cavity (4)

Test #2(before baking)



Standard Material: 2.2 GHz

Test #1:~ 100 mm bcp, 800C, 3 hrs,~ 80 mm bcp

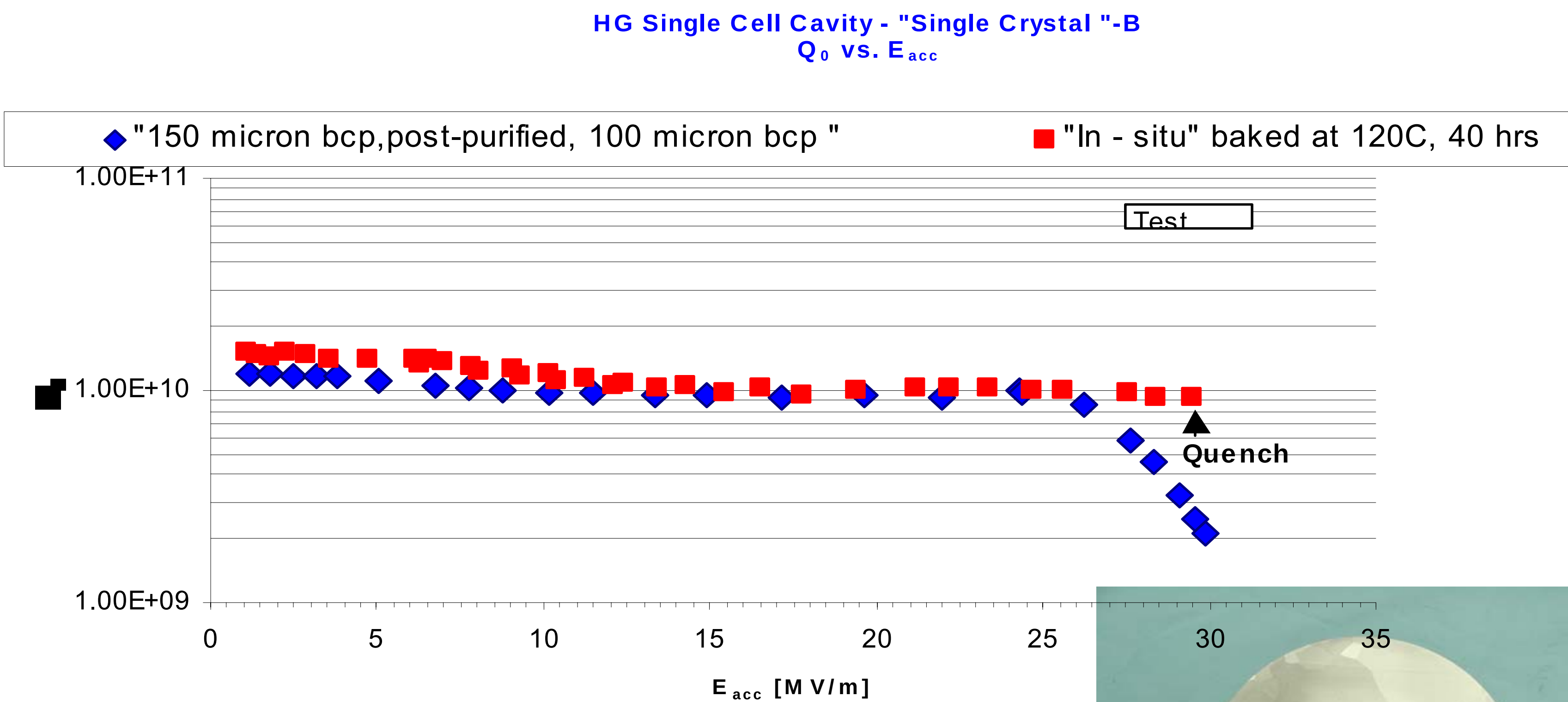


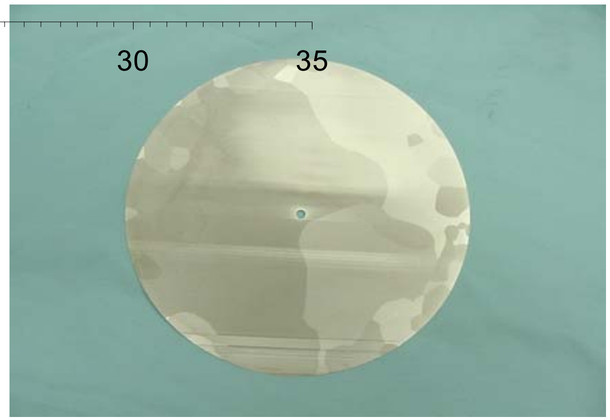
Q-drop: recent observations

- Q-drop is most likely a magnetic field effect
- Heating observed near equator with T-maps
- Is the electron beam weld/contaminated area around weld responsible? (oxide clusters, reduced H_c)
- Elimination of grain boundaries does not eliminate Q - drop, but seem to shift it to larger H_{peak}
- At higher frequencies Q-drop seems to start at higher H_{peak}
- "In situ" baking of EP and BCP cavities reduces Q-drop
- Optimal baking conditions for single crystal/large grain material might need to be adjusted (sometimes increase in R_{res})

Large Grain Niobium (1.5 GHz)

Ingot "B"

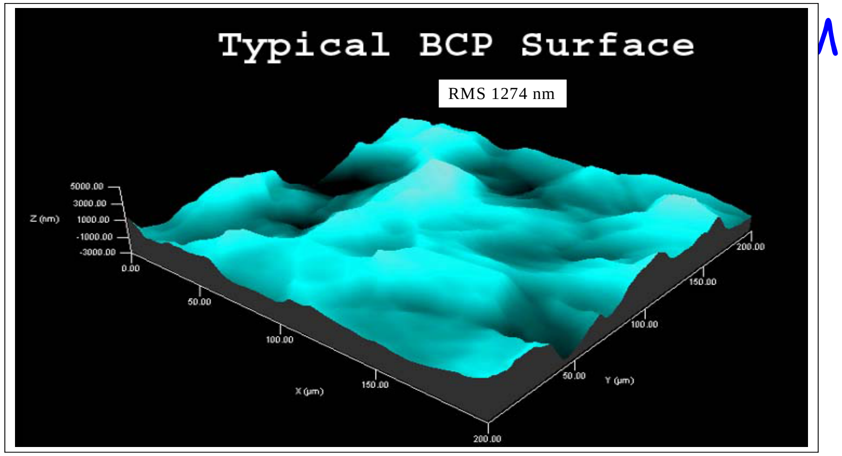


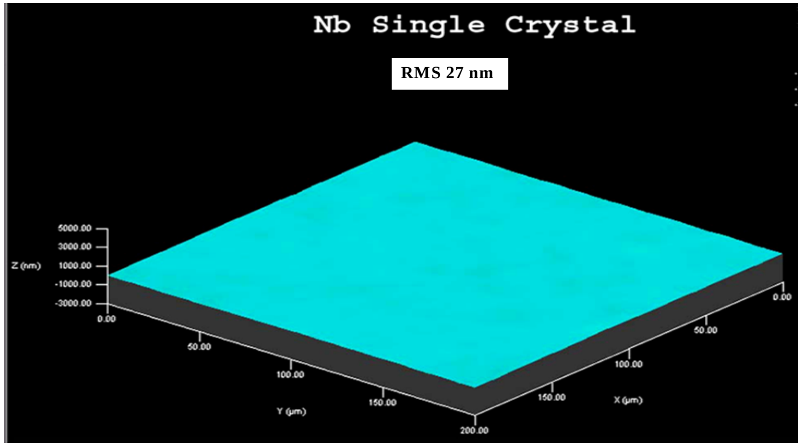


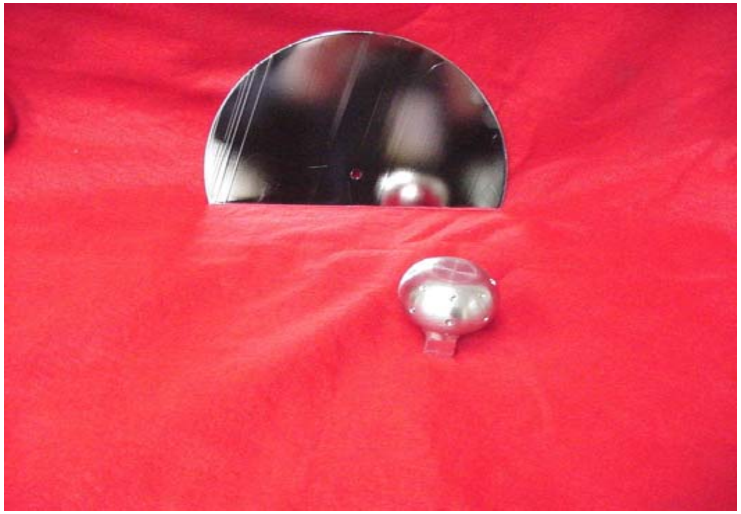
Single Crystal BCP

Provides very smooth surfaces as measured by A.Wu, Jlab

MS: 1274 nm fine grain bcp
27 nm single crystal bcp
251 nm fine grain ep

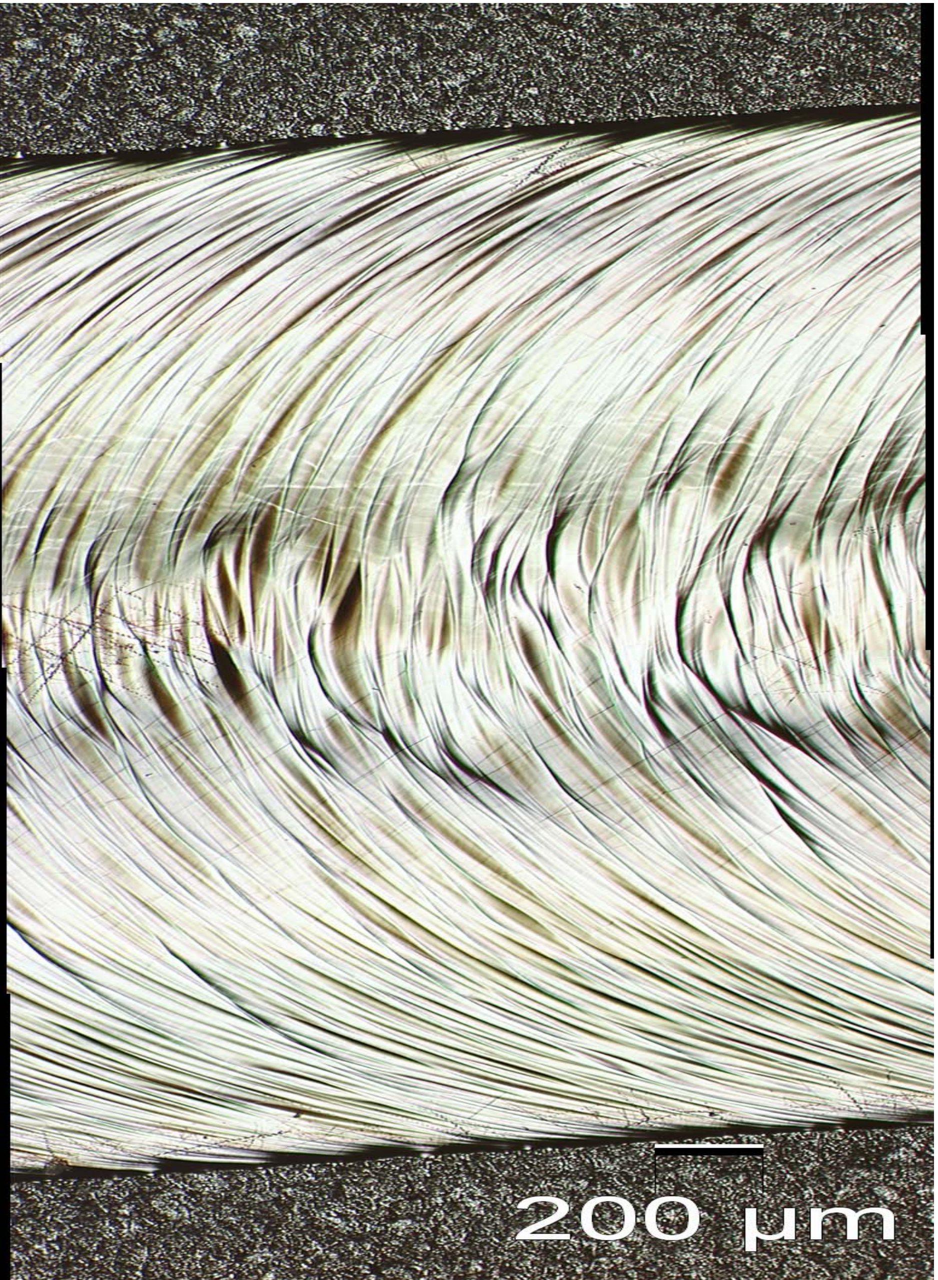




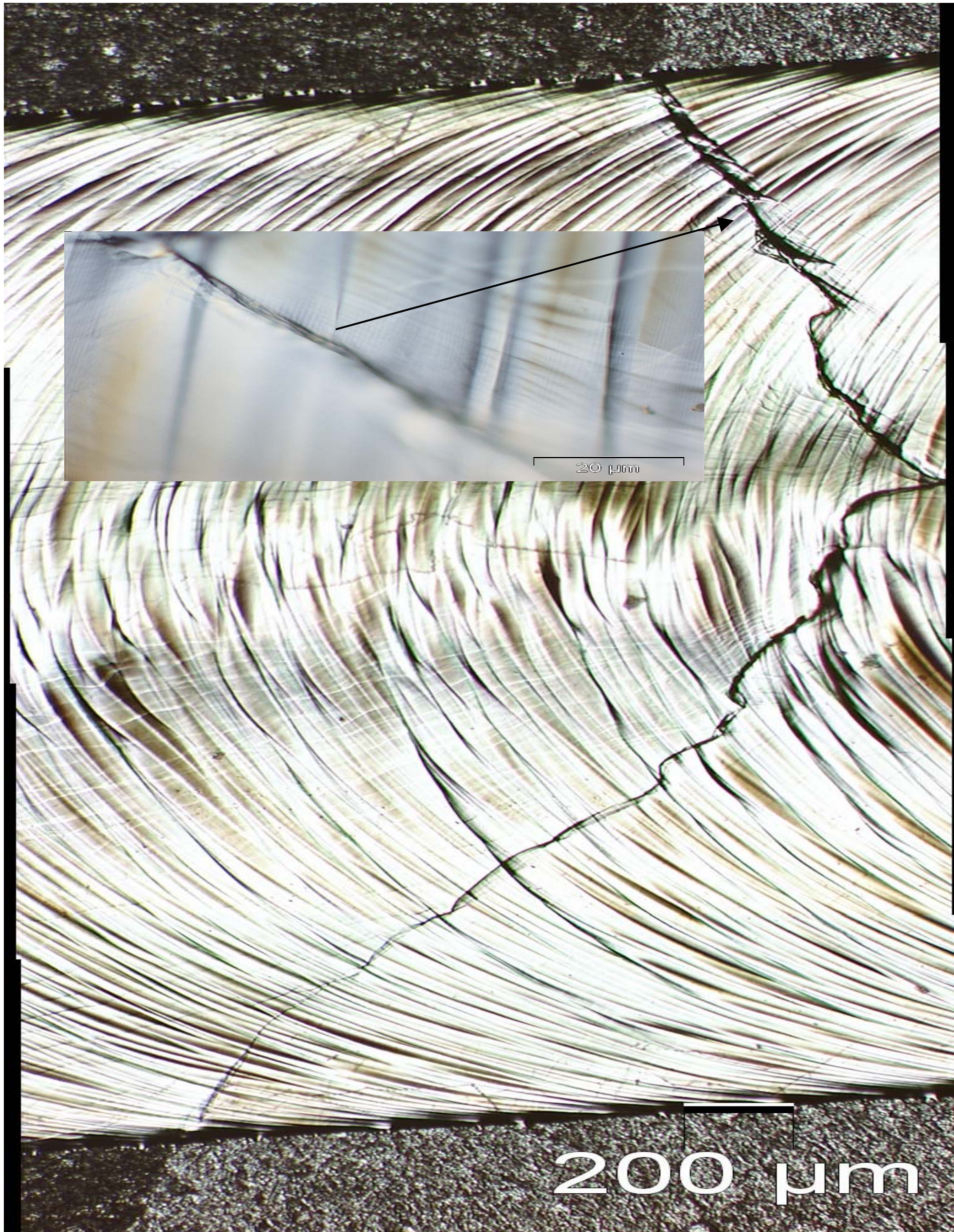


X. Singer

Ein großer Kristall



Korngrenze zwischen zwei Kristallen



Single Crystal Niobium Cavity (10)

Development Program

Material	Cavity/f [MHz]	Status	Results
Single crystal	HG, 2.2 GHz	tested	E_{acc} =38-43 MV/m R_{res} < 1 nΩ
standard	HG, 2.2 GHz	tested	E_{acc} ~35 MV/m $R_{res} \simeq$ 2 nΩ
Single Crystal	LL-ILC, 2.3 GHz	Fabricated, H-degassed	
Large Grain"A"	HG, 1.5 GHz	tested	E_{acc} =32 MV/m R_{res} ~ 7 nΩ
Large Grain"B"	HG, 1.5 GHz	tested	E_{acc} =30 MV/m R_{res} ~ 7 nΩ
Large Grain"A"	7-cell,HG, 1.5 GHz	In fabrication	
Single Crystal	7-cell,LL_ILC 1.3 GHz	Dies in fab Ingot in proc	
Large Grain"A"	HG, 1.5 GHz OC, 1.5 GHz	In fab, Saw cut	

Outlook for WG1+2

- We will have some homework assigned:
  - Convenors of WG1+2 made a list of R&D topics for a next-generation cavity preparation infrastructure
    - http://elan.desy.de (ELAN SRF Work package)
    - and on the server with the talks for this meeting linked to either ilc.desy.de or tesla.desy.de
  - Next steps:
    - Comments should be send to lutz.lilje@desy.de before the ILC-BDIR Workshop in London
      - » June 19th 2005
    - Comments should be
      - » Missing topics (for cavity preparation)
      - » Interests should be flagged
    - We hope to get a discussion slot at SRF 2005
    - After this follow-up on the WGs 1+2 at the next TESLA technology colloboration meeting

Cavity preparation	System		Topic	Needed R&D	Working parties
	Optical inspection	mandatory	QC	mass production issues	
	Dimensional inspection	mandatory		mass production issues	
	Frequency tuning	mandatory	QC	mass production issues	
	Cleanroom	mandatory	clean handling and assembly	QC issues	
				Procedures for personal	
				Adaption of the cleanroom to the product e.g. logistics	
				Cleanroom-compatible tooling	
				Tooling with semi-automation options	
	Ionized N2 cleaning	mandatory	component cleaning	mass production issues	
				automation desirable	
	Ultrasound	mandatory	component cleaning	mass production issues	
	Resistivity rinse	mandatory	component cleaning	mass production issues	
	Ultra-pure water system	mandatory	component cleaning	large-scale, redundancy	
				hot water rinsing	
	HPR	mandatory	final cavity cleaning	redesign after all the lessons learned	
				reliable operation, design for high throughput, redundancy, maintainability	
				online monitoring (TOC, Particles, Resistivity, sample port)	
				optimum parameters	

Part B

A preliminary list of requirements for a new superconducting cavity preparation infrastructure

Cavity preparation	System		Topic	Needed R&D	Working parties
	Optical inspection	mandatory	QC	mass production issues	
	Dimensional inspection	mandatory		mass production issues	
	Frequency tuning	mandatory	QC	mass production issues	
	Cleanroom	mandatory	clean handling and assembly	QC issues	
				Procedures for personal	
				Adaption of the cleanroom to the product e.g. logistics	
				Cleanroom-compatible tooling	
				Tooling with semi-automation options	
	Ionized N2 cleaning	mandatory	component cleaning	mass production issues	
				automation desirable	
	Ultrasound	mandatory	component cleaning	mass production issues	
	Resistivity rinse	mandatory	component cleaning	mass production issues	
	Ultra-pure water system	mandatory	component cleaning	large-scale, redundancy	
				hot water rinsing	
	HPR	mandatory	final cavity cleaning	redesign after all the lessons learned	
				reliable operation, design for high throughput, redundancy, maintainability	
				online monitoring (TOC, Particles, Resistivity, sample port)	
				optimum parameters	
				nozzle parameters	
				FE sample scans	
	Etching	mandatory	min. outside etch	mass production issues	
			evt. Inside etch		
	EP	mandatory	high gradient	optimum parameters (acid mix, electrode shape)	
			reliable operation	Acid QC e.g. online HF monitoring	
				temperature stabilization (heat exchanger)	
				voltage/current/potentiometric control?	
				EP samples: FE scans, roughness measurement	
	In-situ baking	mandatory	high gradient	Magnetic or electric field effect	
				grain boundary effect	
				equator weld problem	
				optimum conditions	
	furnace treatments	mandatory	800 C: stress, hydrogen		
		option	1400 C: post-purification		
	Dry-ice cleaning	option	higher efficiency, horizontal cleaning	Demonstration of horizontal cleaning	
				Multi-cell demonstration	
	Barrel polishing	option	less material removal	Multi-cell demonstration	
	Megasonic	option	higher cleaning efficiency	try on cavities	

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