

Status of the XFEL test cavity program

Detlef Reschke

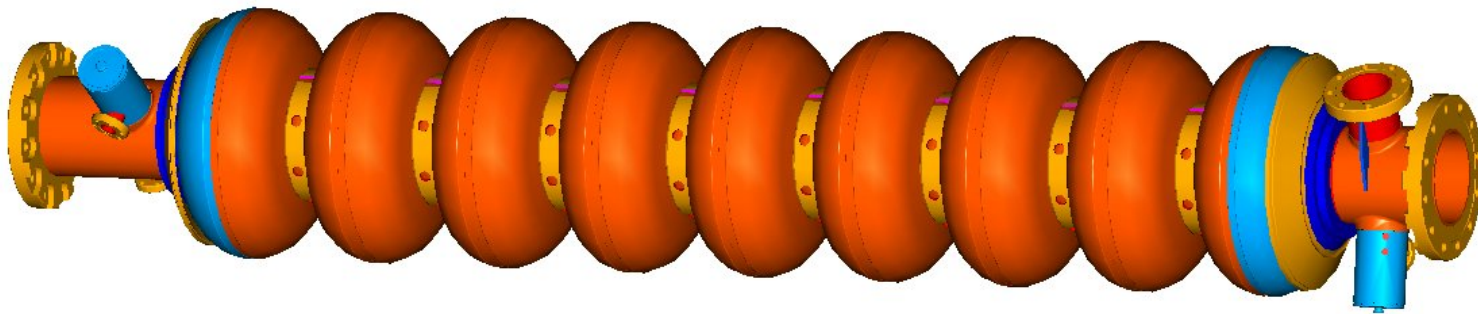
for the test cavity program team

July 2006

- Motivation
- Object of the program
- Status + Results
- Summary, next steps + some problems

Motivation

- XFEL will be based on today's nine-cell cavities (no super-structure, no major modifications of inter-cavity connection,.)



- Specification for cavity fabrication: 2006

=> Qualification of modified fabrication parameters is urgent

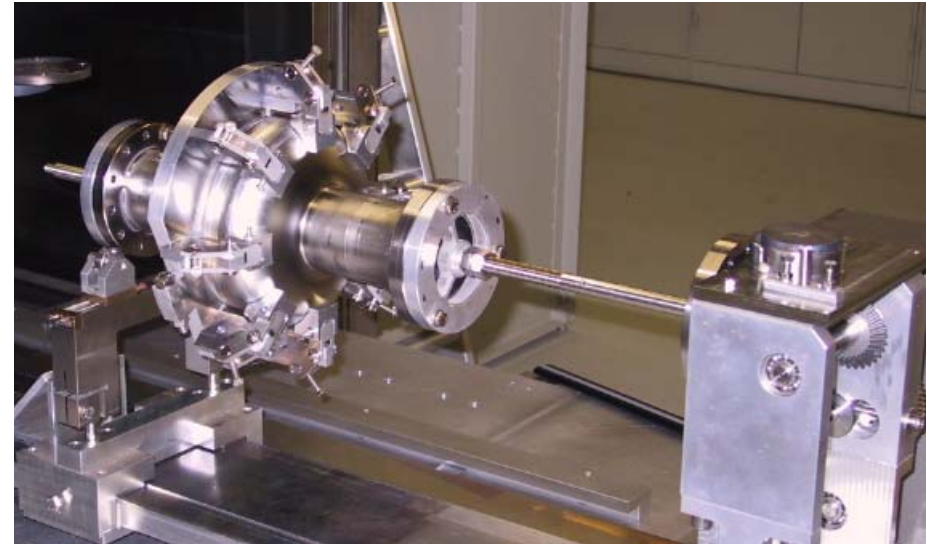
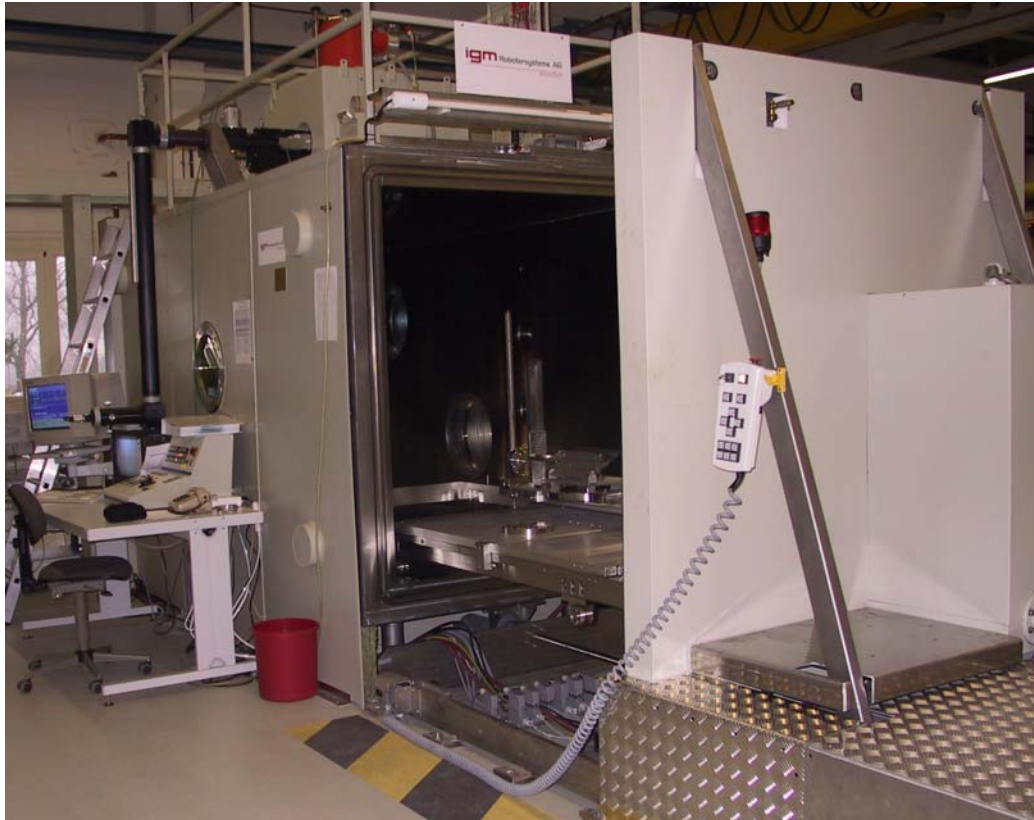
=> Qualification of further Nb vendors

=> large-crystal Nb for series nine-cell production ?

Object of the program

- Modification of present spec for welding preparation during cavity fabrication:
 - up to now:
max 8h between final etching of weld area and EB welding (“8h – Regel”)
=> restriction of cavity fabrication workflow
 - new:
test of storage of prepared (etched + dried) components for **1 week under vacuum and nitrogen** atmosphere

Electron beam welding at DESY



Object of the program (ctd.)

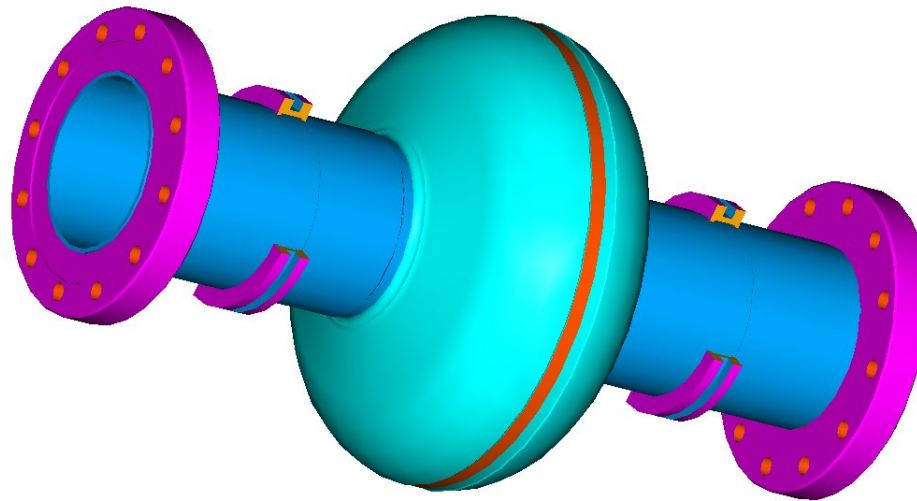
- Large grain niobium:
 - application of “large grain” (**cm-size**) niobium disks cut from ingot (instead of forged and rolled sheets with grain size of $\sim 100\mu\text{m}$)
=> ingots from Hereaus, Ningxia, CBMM
 - **test of mono-crystal** niobium (two cavities)
- Qualification of further niobium vendors:
 - Heraeus stopped fabrication of Nb sheets; only ingots available
=> **sheets by Plansee Co. need to be qualified urgently**
 - check of chinese Ningxia niobium
 - check of Cabot niobium, but RRR spec not met
 - check of russian Giredmet niobium with high RRR + low tantalum
=> availability of large quantities??

Object of the program (ctd.)

- Comparison of EP processes at Henkel + DESY
 - different and complex behavior of electrolytic bath (1 part HF : 9 parts H_2SO_4)
=> study of parameters, electrolyte, set-up
- Development of dry-ice cleaning as additional cleaning process (CARE,...)
- Check + optimisation of “120C-bake” parameters
- Further activities:
 - second s.c. photo cathode gun cavity with 0.6-cells (Jacek Sekutowicz)
 - optional: extension to 1.6-cell s.c. gun cavity
 - prototype of three-cell cavity

Status and Results

- DESY standard single-cell cavity:



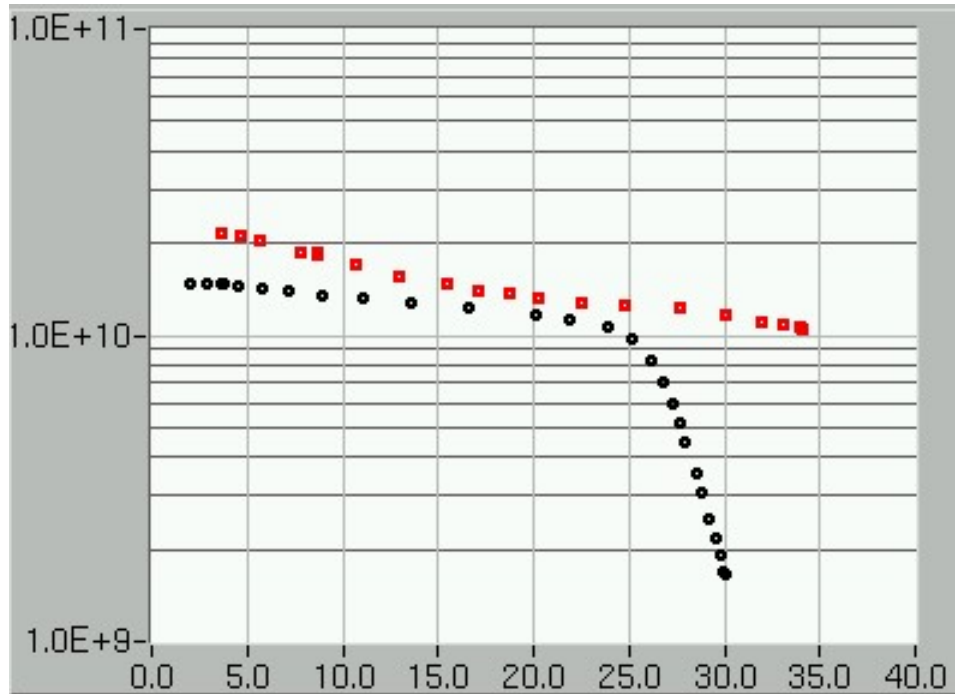
- 16 cavities at DESY completed:
 - machining, etching, EB welding + mechanical/optical checks inhouse
 - deep drawing of cups and electropolishing (EP) of cavities in industry
- 6 cavities at Accel Co. completed (large grain + mono crystal):
 - final mechanical/optical checks at DESY; EP at Henkel Co.; BCP at Accel

Status + Results: Qualification of DESY production

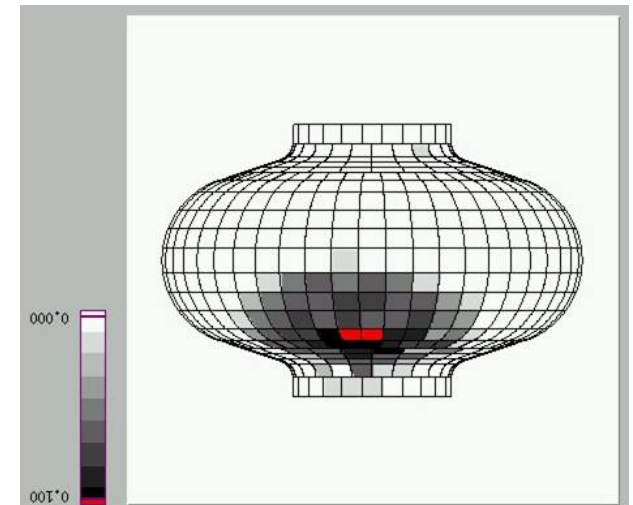
- First step: Qualification of DESY in-house production:
 - 3 single-cells of well-known Nb quality (Heraeus 1999)
 - deepdrawing of cups at Zanon Co.
 - All electropolishing at Henkel Co.
 - Assembly, HPR and tests at hall NO
- all cavities exceed 30 MV/m at high Q-value
- Example for cavity data presentation

1DE1: First DESY-Cavity successful

- First Cavity of DESY inhouse fabrication
- 150 μ m EP@Henkel, 800C, 130 μ m EP@Henkel, HPR, 127C bake, HPR
(i) 130 μ m EP due to grinding; ii) add. HPR after bake necessary due to field emission)
 $E_{\text{acc}} = 34 \text{ MV/m} @ Q_0 = 1 \cdot 10^{10}$; no FE; limited by BD; few MP



Q(E)-curves before and **after** bake at $T = 2\text{K}$

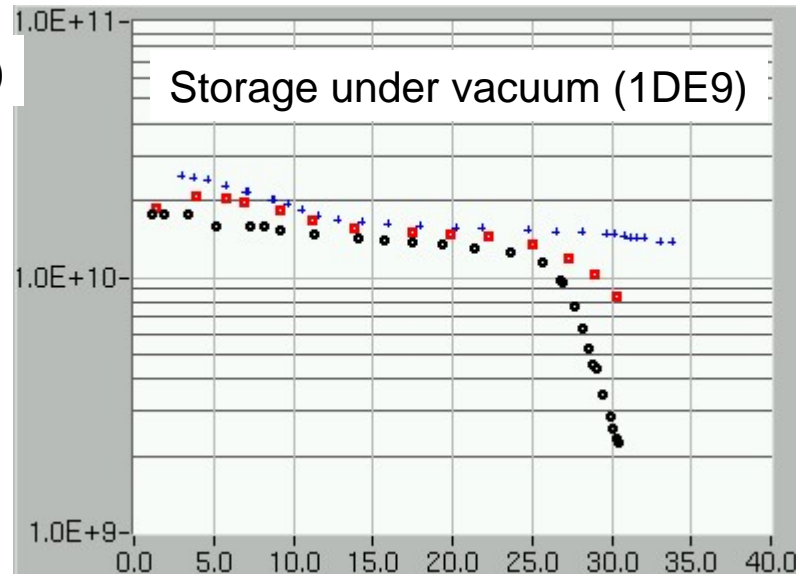
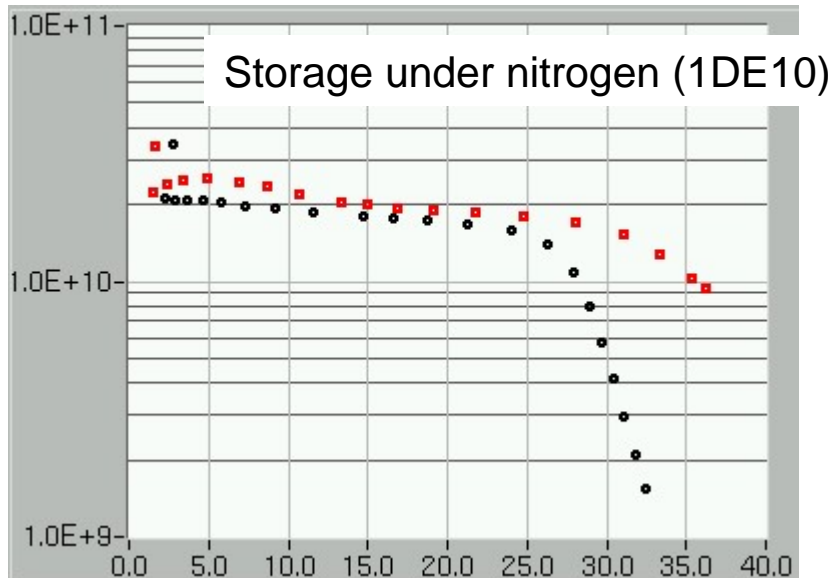
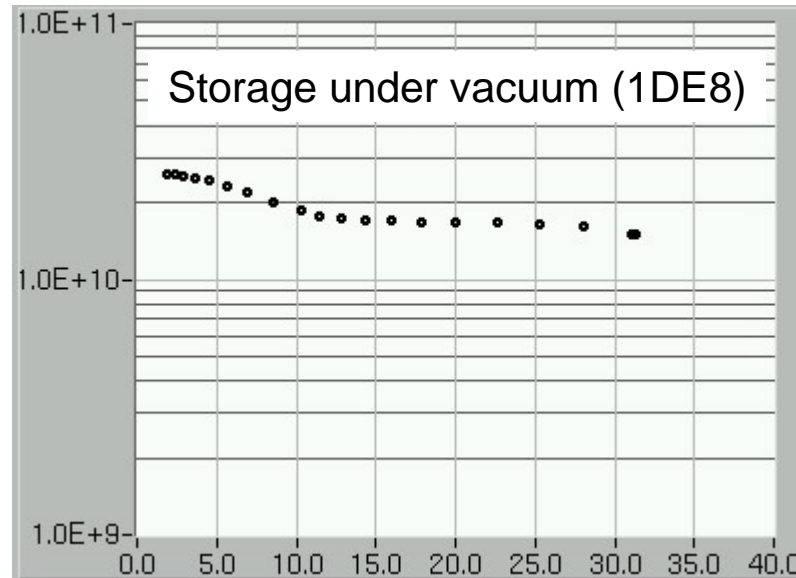
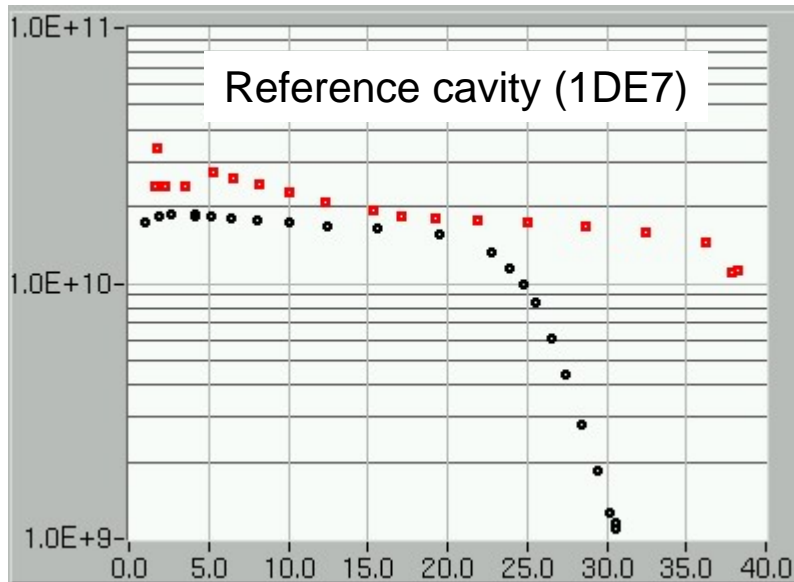


Quench location far off the equator

Status and Results: Welding preparation

- Modification of present spec for welding preparation during cavity fabrication:
 - 1x reference cavity: max 8h between final etching of weld area and EB welding; (tested)
 - 2x cavities with 168h storage under vacuum of components after final etch of weld area; (2x tested)
 - 2x cavities with 168h storage under nitrogen atmosphere of components after final etch of weld area; (1x tested; 1x ready for test)
- Good cavity performance with gradients between 31MV/m and 38 MV/m!!
- Modified welding preparation is accepted !!

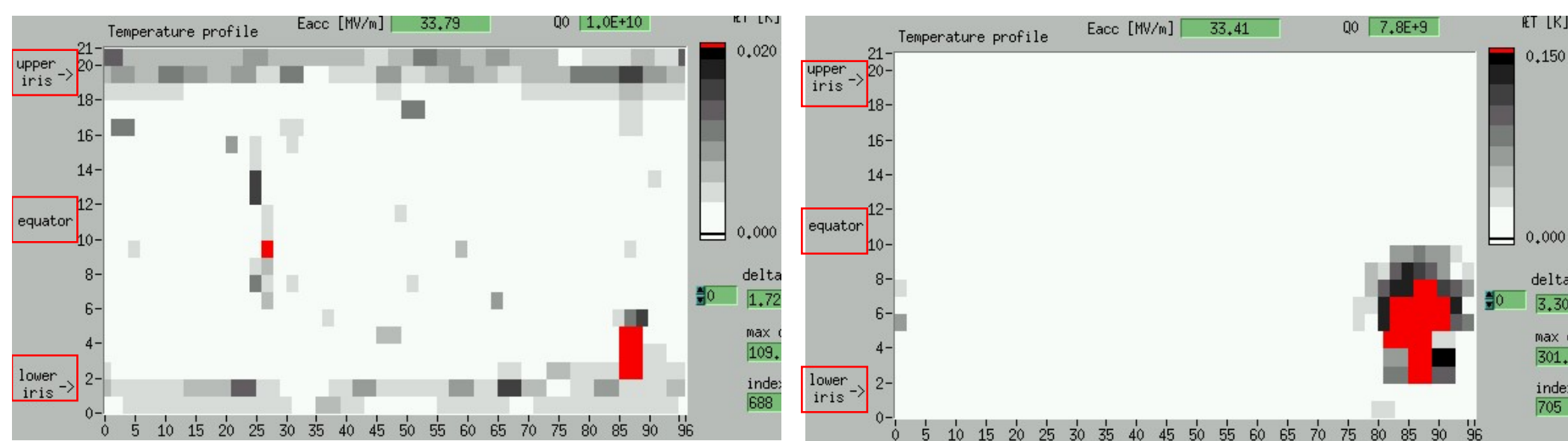
Status and Results: Welding preparation II



Q(E)-curves at 2K
before and after
bake at app. 130C

Quench location (1DE7, 1DE9)

- Reference cavity 1DE7: T-Maps after bake (test 2):
 - a) T-Mapping shows remaining field emission and pre-cursor of quench
 - b) T-Map during quench at 33,5 MV/m; quench located well-off the equator

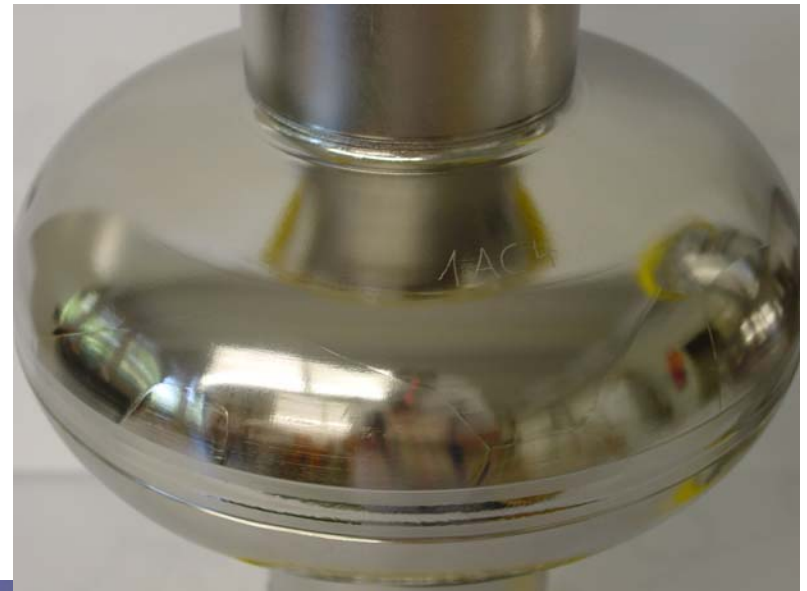


T-maps just before (left) and during (right) quench

- Remark: Max. gradient of 38 MV/m in test 5 without T-Map.

Status and Results: Large grain material

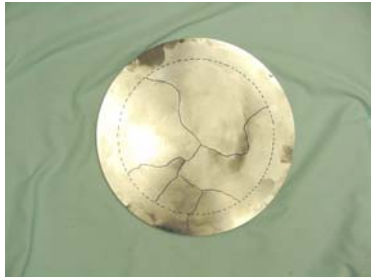
- Five single-cell cavities + three nine-cell cavities fabricated at Accel Co. of “large grain”-Nb by Heraeus with RRR = 500 (two Nb batches/ingots)
- First tests after electropolishing due to
 - i) availability of BCP vs. EP facilities
 - ii) comparison to P.Kneisel’s large grain results after BCP
 - CBMM, Wah Chang + Ningxia niobium at 2,2GHz / 1.5GHz / 1.3GHz
 - 8 – 10 cavities of different cavity shapes => $E_{acc} = (25 - 34) \text{ MV/m}$
- add. tests after BCP ongoing
- significant mechanical problems during deep-drawing (shape + tolerances !!!)



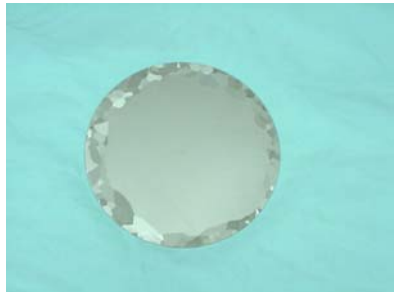
Courtesy by Peter Kneisel

Large Grain/Single Crystal Niobium[2]

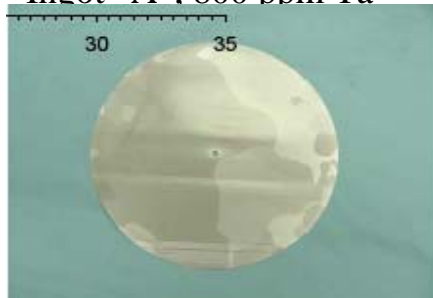
CBMM



Ingot "D", 800 ppm Ta



Ingot "A", 800 ppm Ta



Ingot "B", 800 ppm Ta

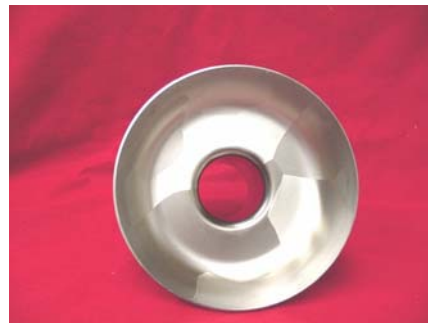
Ninxia



Wah Chang



Heraeus



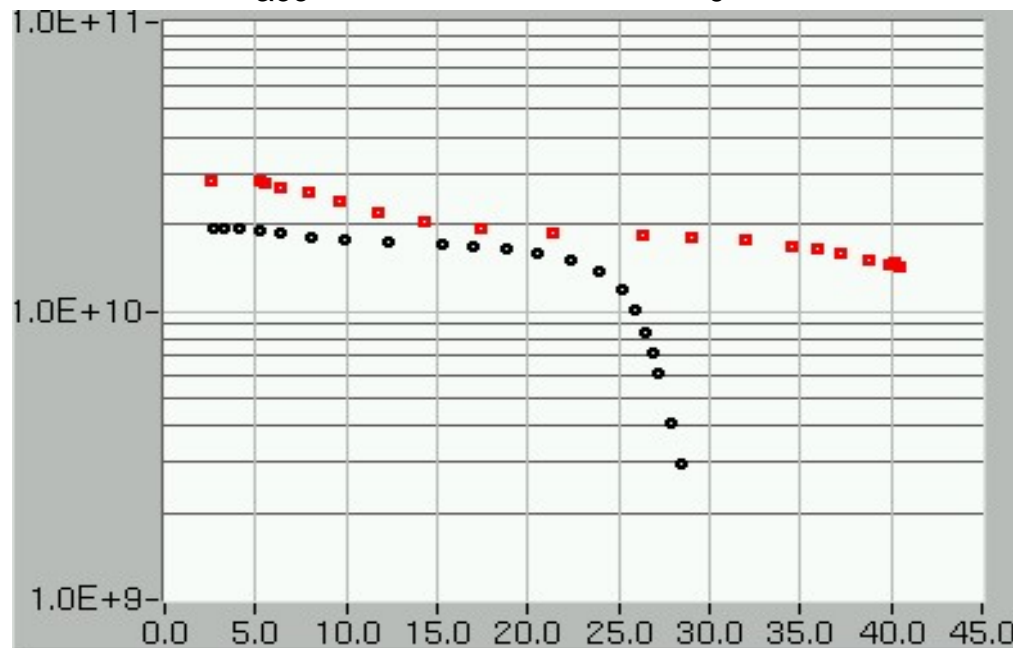
Ingot "C", 1500 ppm Ta



28.07.2006

Summary of large grain cavity 1AC3

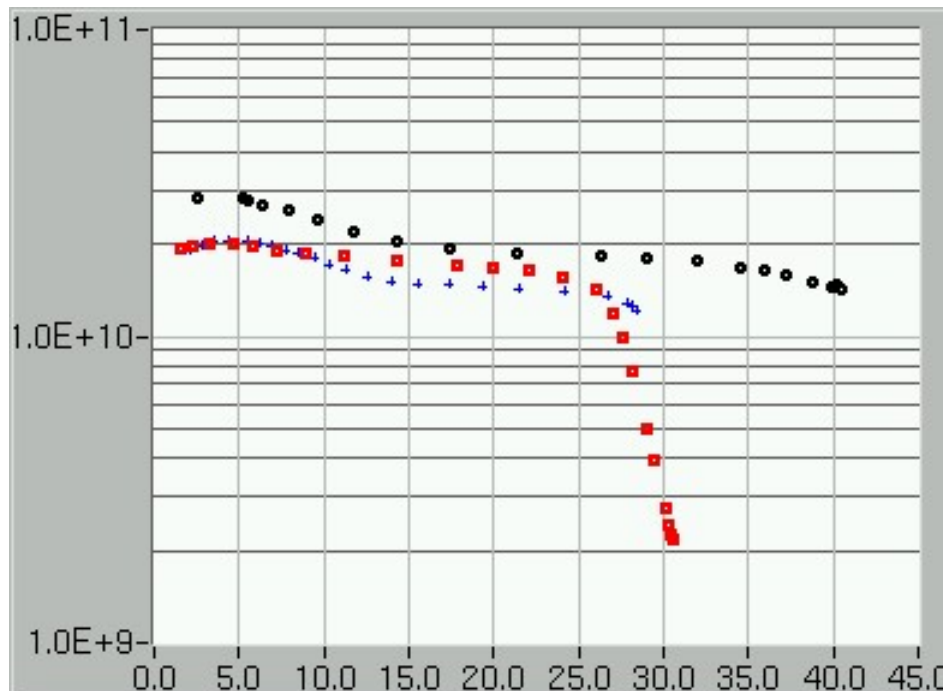
- large grain Heraeus Nb RRR 500 cut from ingot; fabrication at Accel Co.
- Test 1: 150 μ m EP@Henkel, 800C, 40 μ m EP, HPR:
 $E_{\text{acc}} = 28,4 \text{ MV/m @ } Q_0 = 3 \cdot 10^9$; **FE** (>25 / n.a.MV/m) ; limited by pwr
- Test 3: baking at 120C,48h + add. HPR (test 2 limited by field emission):
 $E_{\text{acc}} = 41 \text{ MV/m @ } Q_0 = 1,4 \cdot 10^{10}$; **no FE** ; limited by bd



Q(E)- curves at 2K before and **after** bake

1AC3 test 4 + 5 after BCP

- Test 4: 42 μm BCP, grinding of beam tube, 10 μm BCP, HPR:
 $E_{\text{acc}} = 30,5 \text{ MV/m}$ @ $Q_0 = 2,2 \cdot 10^9$; no FE; limited by power
- Test 5: add. bake 133C
 $E_{\text{acc}} = 28,5 \text{ MV/m}$ @ $Q_0 = 1,2 \cdot 10^{10}$; no FE; limited by **Quench**



Q(E)-curves at 2K:

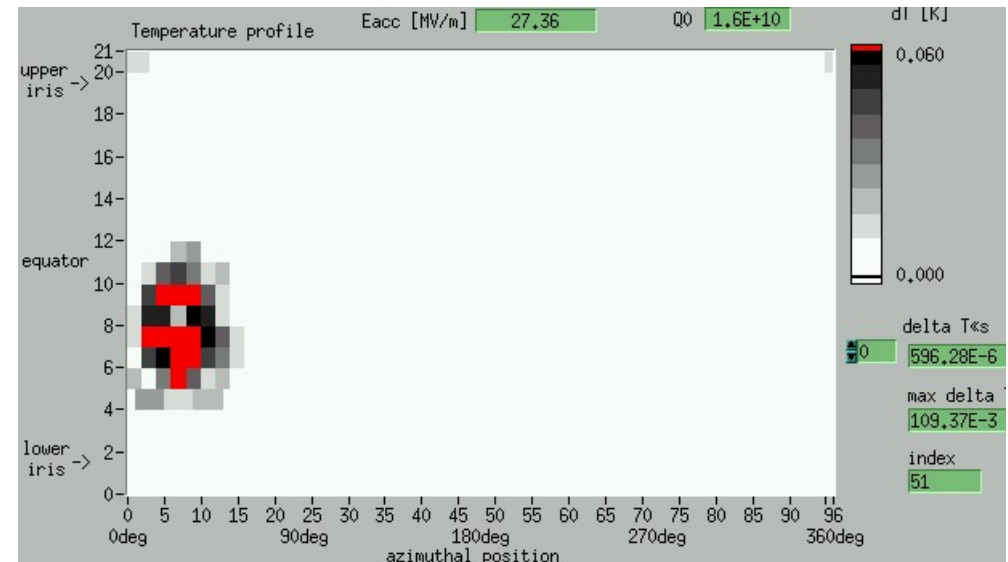
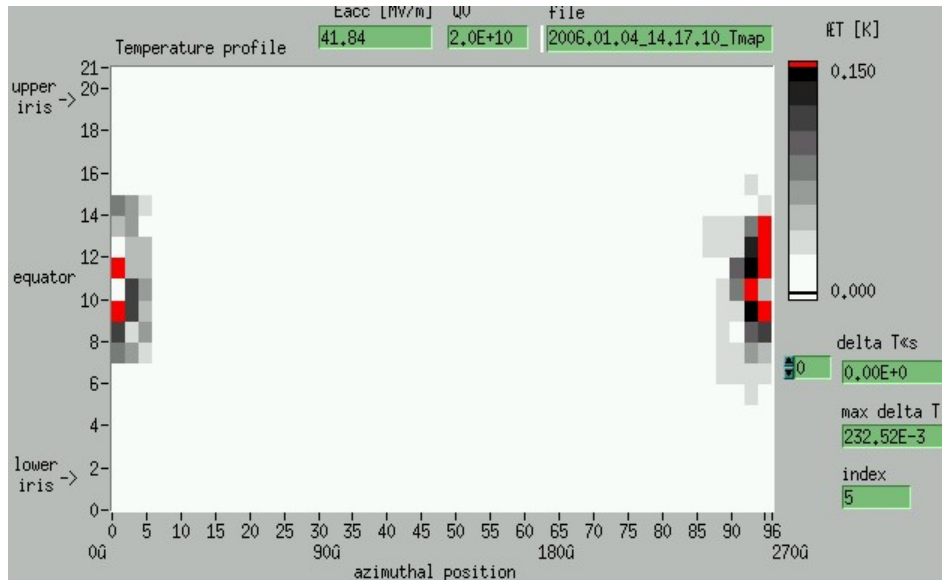
- **after BCP before bake**
- **after BCP + after bake**
- final curve after EP

Remark:

Decrease of 2MV/m after bake
is compatible with test error !!

1AC3 test 5 after BCP + bake: T-Maps

- Comparison of T-Maps during **quench** of test 3 and test 5:

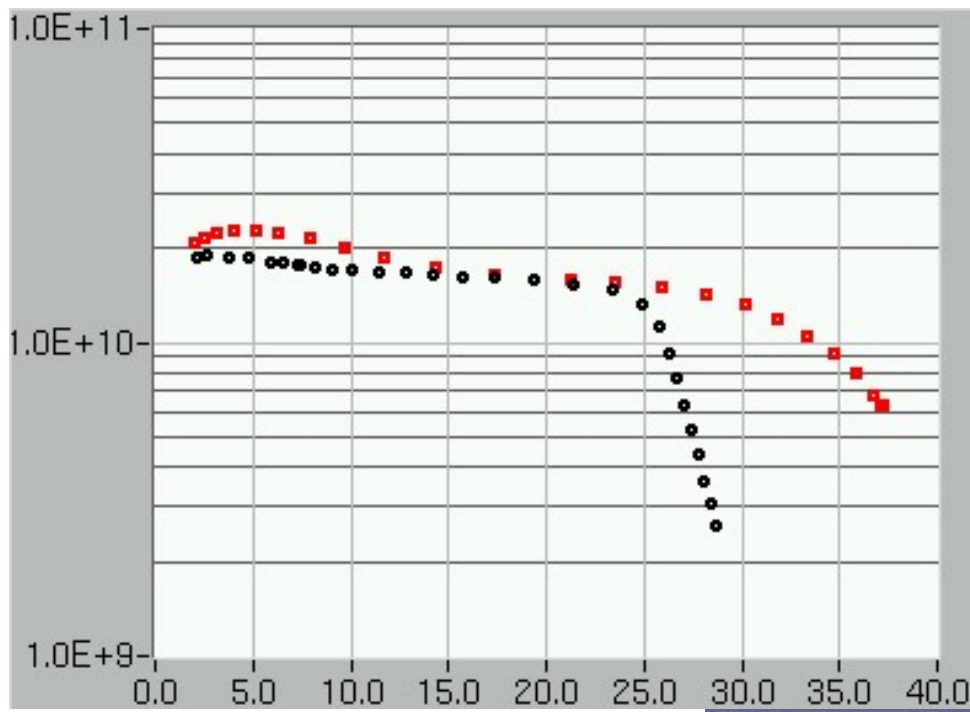


Test 3: $E_{acc} = 41 \text{ MV/m}$ @ $Q_0 = 2 \cdot 10^{10}$; no FE Test 5: $E_{acc} = 28,5 \text{ MV/m}$ @ $Q_0 = 1,2 \cdot 10^{10}$; no FE

- **Changed quench location after BCP !!!**

Summary of large grain cavity 1AC4

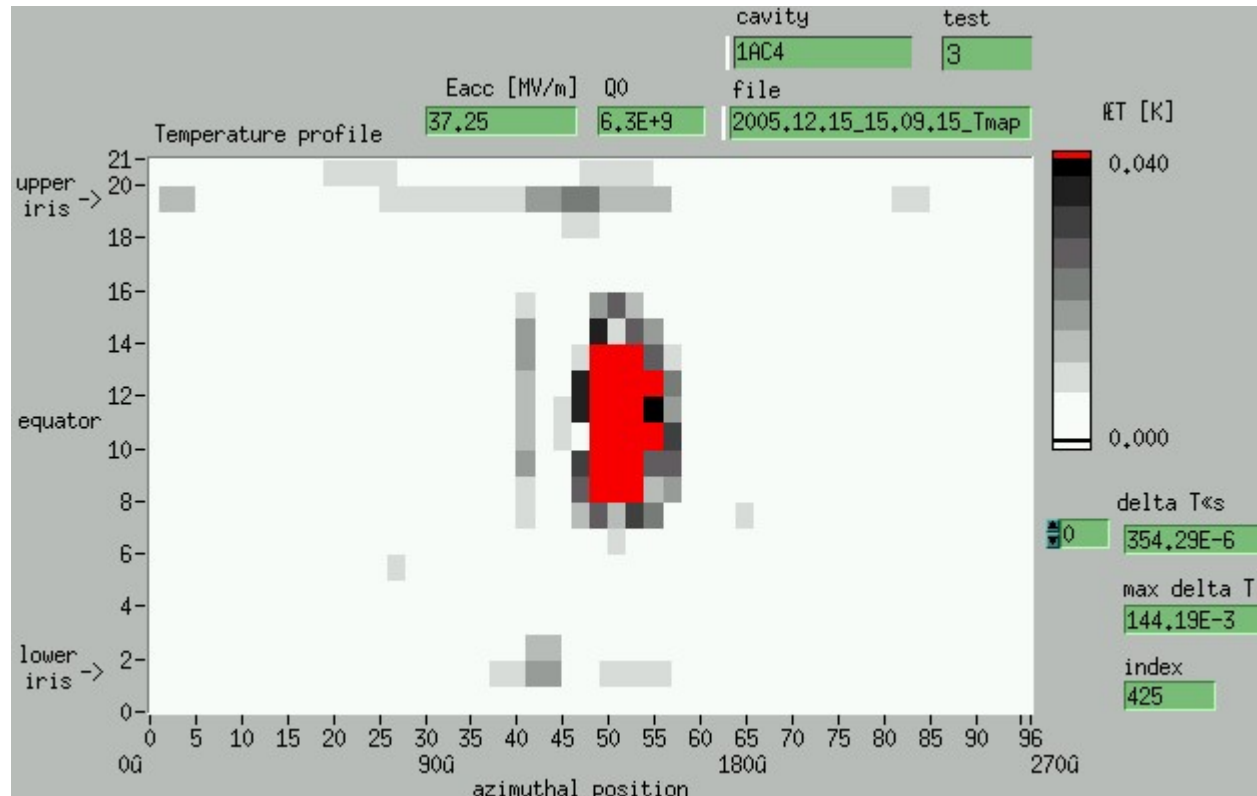
- large grain Heraeus Nb RRR 500 cut from ingot; fabrication at Accel Co.; EP at Henkel Co.
- Test 2: 150 μ m EP, 800C, 40 μ m EP, HPR (test 1 stopped due to cryostat problem)
 $E_{\text{acc}} = 29 \text{ MV/m} @ Q_0 = 3 \cdot 10^9$; no FE, no MP, limited by pwr
- Test 3: baking at 128C, 48h:
 $E_{\text{acc}} = 37,2 \text{ MV/m} @ Q_0 = 6,3 \cdot 10^9$; FE (>28 / 36MV/m); limited by quench



Q(E) - curves at 2K
before and **after** bake

1AC4: T-Maps of test 3

- T-Map no. 13 of test 3 at 37 MV/m during Quench:



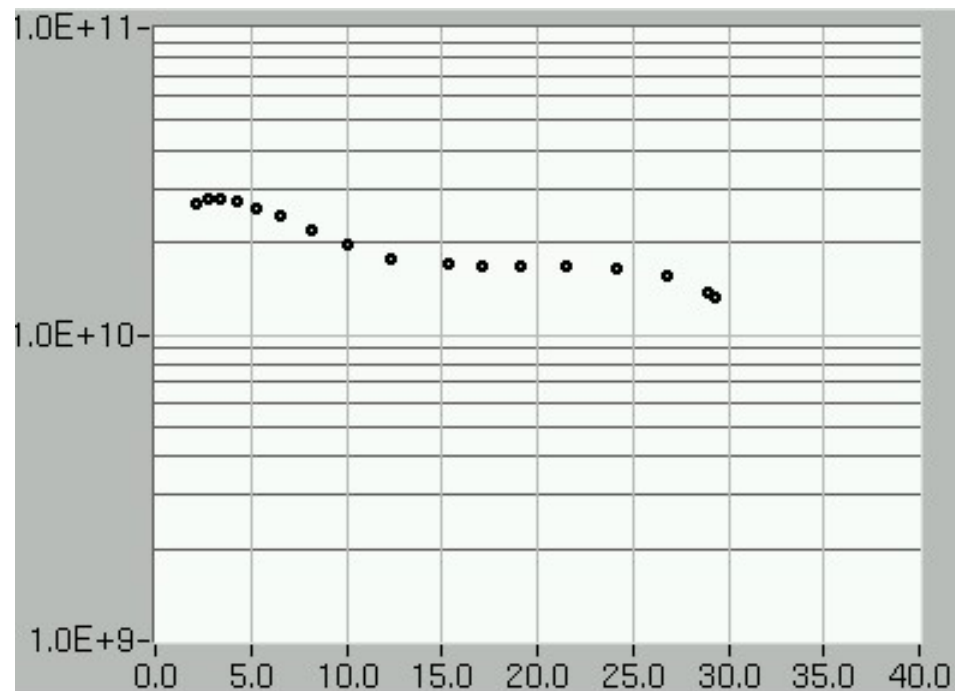
- i) quench location around the equator dominating
- ii) trace and hot spots of field emission clearly visible

1AC5: Summary of first test

- large grain Heraeus Nb cut from ingot; fabrication at Accel Co.: **spun cups**; EP at Henkel Co.
- Test 1: 150 μ m EP, 800C, 40 μ m EP, HPR, 135C bake, HPR (T-Maps):
 $E_{acc} = 29,3 \text{ MV/m}$ @ $Q_0 = 1,3 \cdot 10^{10}$; few FE (>28 / -), no MP, lim. by Quench
no Q-disease

=> significant worse Q(E)-
performance compared
to 1AC3 + 1AC4

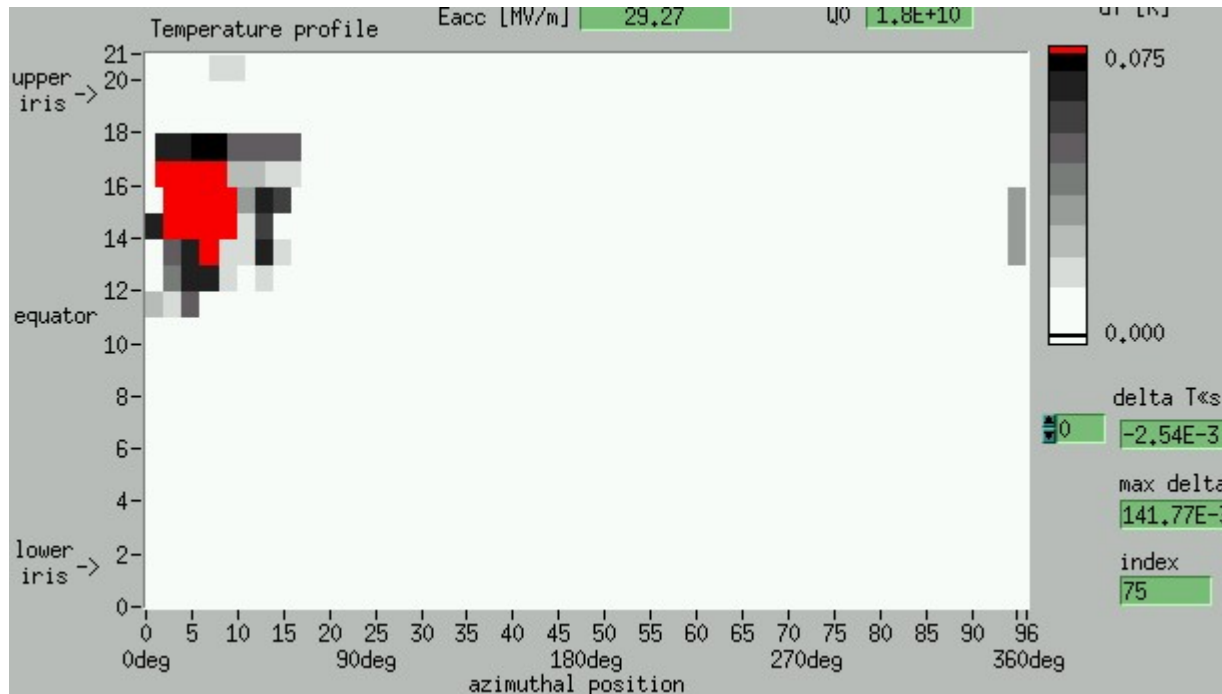
=> fabrication problems of
spun cups ??



Q(E) - curve at 2K **after** bake

1AC5 test 1: T-Maps

- Test 1: $E_{\text{acc}} = 29,3 \text{ MV/m}$ @ $Q_0 = 1,3 \cdot 10^{10}$; few FE (>28 / -), lim. by Quench

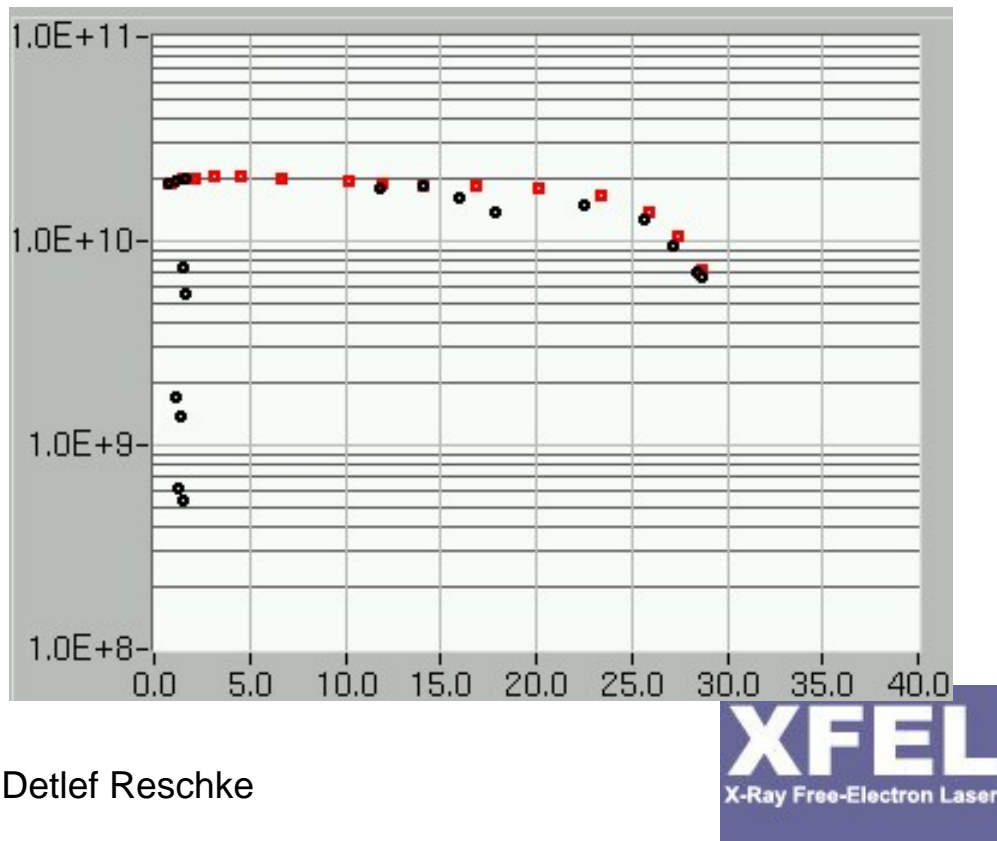


T-Map at 2K
after Q-disease check

=> Quench far off the equator !!

Nine-cell AC114: Summary of first tests

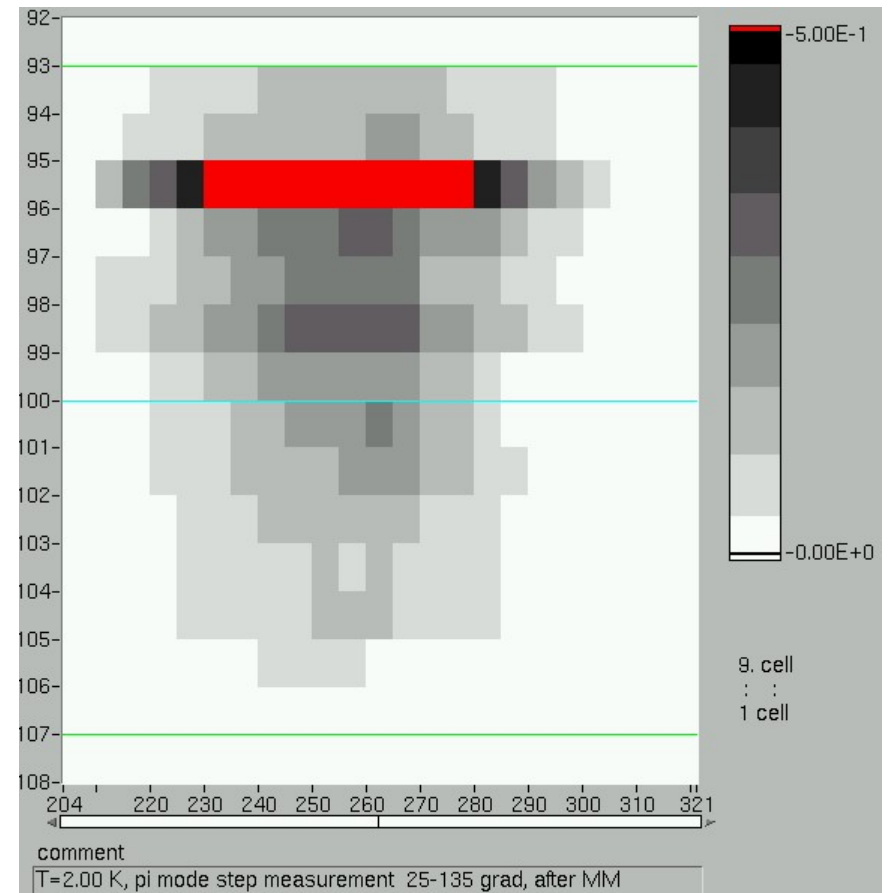
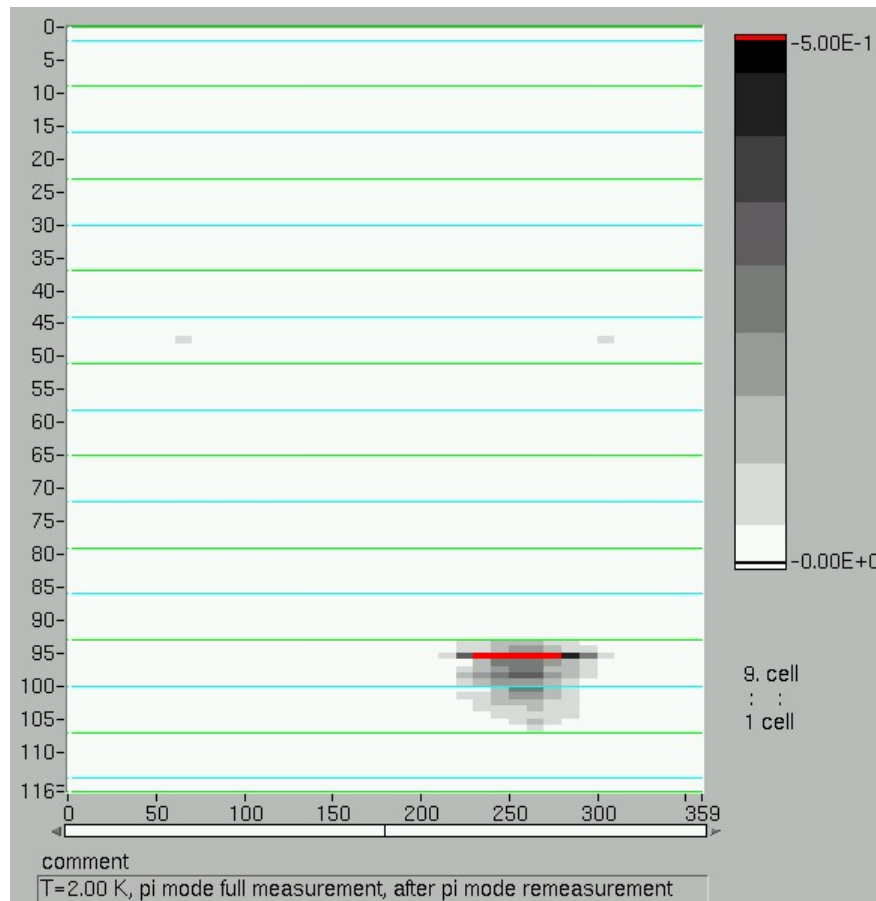
- large grain Heraeus Nb cut from ingot (**different ingot than 1AC3-5**); RRR ca. 500; fabrication at Accel Co.; deep drawn cups, BCP at DESY
- Test 1: 100 μ m BCP, 800C, 20 μ m BCP, much HPR (T-Maps):
 $E_{acc} = 28,7 \text{ MV/m} @ Q_0 = 7,3 \cdot 10^9$; **strong FE (>18 / 23)**, LPP at 2MV/m observed; no Q-disease; lim. by Quench => **FE induced???**



First and **final** Q(E) - curve at 2K

Nine-cell AC114 test 1: T-Maps

- T-Maps at 2K during Quench (after mode measurement)



=> Quench in cell 2, upper cup, between iris and equator

=> FE- induced quench??

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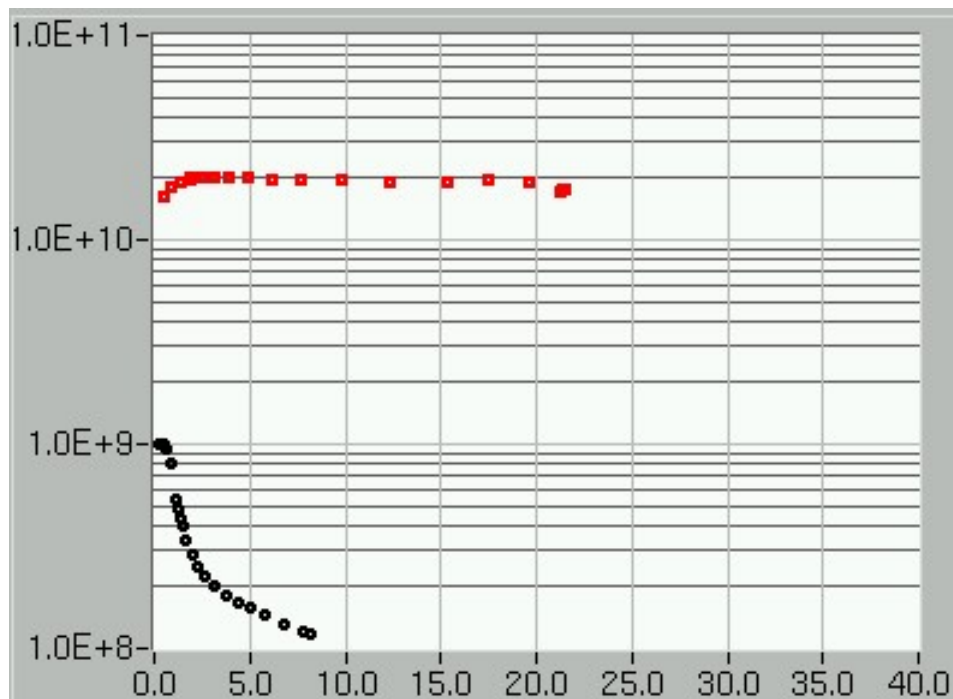
AC114: Mode measurement of test 1

			Best CW-Test						
Cavity	Prod No	Cells	BCP/EP Cavity	CW-Test Date	Max. Eacc	Qo at Max. Eacc	Limit	FE Onset	Eacc at Q=1e+10
AC114	5	ALL	BCP	07-Jul-06	28.74	6.5E+09	bd	17.50	27.22
		1&9			32.36			bd	
		2&8			31.68			bd	
		3&7			36.03			bd	
		4&6			32.89			bd	
		5			32.98			bd	

- All cells are quench limited
 - All cells have higher max. E_{acc} than pi-mode
- => inconsistency caused by influence of FE

First mono-crystal cavity (1AC6)

- Single crystal CBMM Nb with RRR 200; fabrication at Accel Co.
- Test 1: 140 μ m BCP, HPR:
 $E_{acc} = 8 \text{ MV/m @ } Q_0 = 1,2 \cdot 10^9$; **strong Q-disease due to EDM cutting**
- Test 2: add. 750C heat treatment, 30 μ m BCP, HPR:
 $E_{acc} = 21,5 \text{ MV/m @ } Q_0 = 1,8 \cdot 10^{10}$; **limited by quench**, no FE



=> next test after more BCP

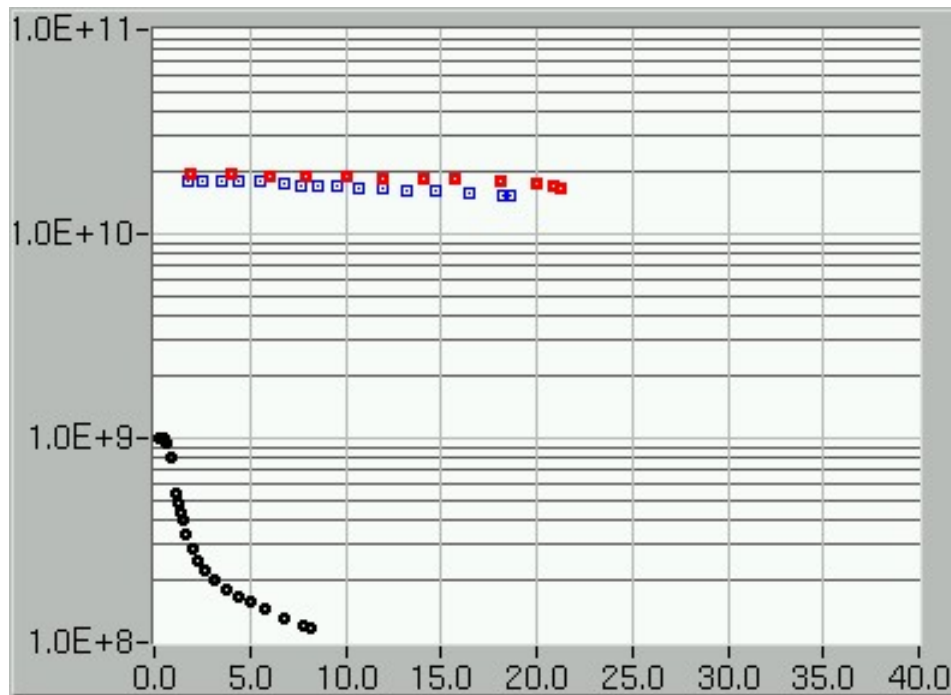
Q(E) - curves at 2K before
and **after** 750C + 30 μ m BCP

Single-crystal 1AC6: test 3 after add. BCP

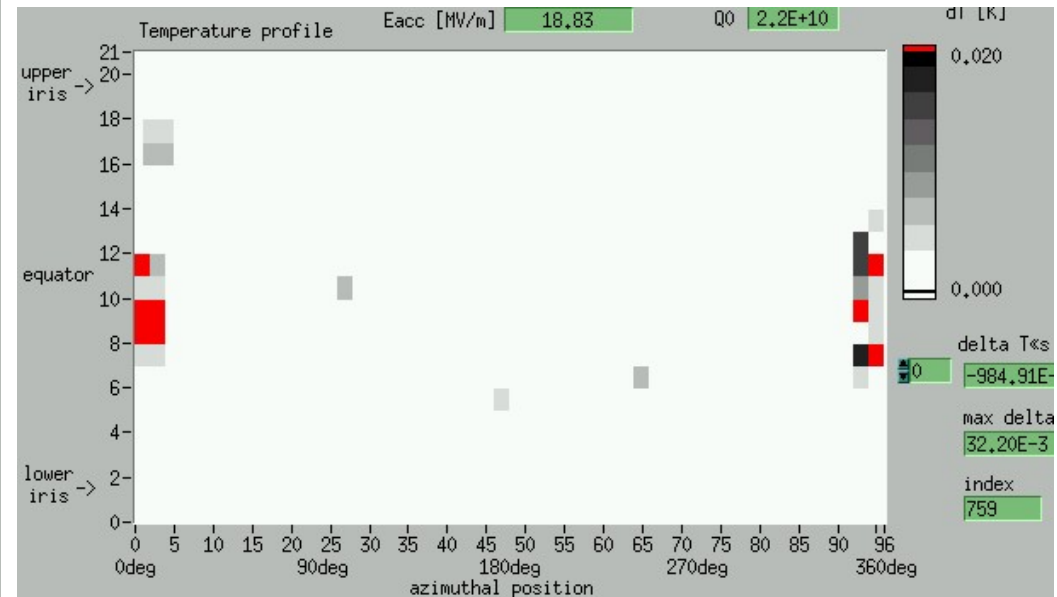
- Test 3: 66 μ m BCP, grinding (?), 26 μ m BCP, HPR:

$$E_{\text{acc}} = 18,6 \text{ MV/m @ } Q_0 = 1,6 \cdot 10^{10}; \text{ limited by quench, no FE}$$

=> next test after EP



Q(E) - curves at 2K before
and **after 750C + 30 μ m BCP**,
after add. 92 μ m BCP



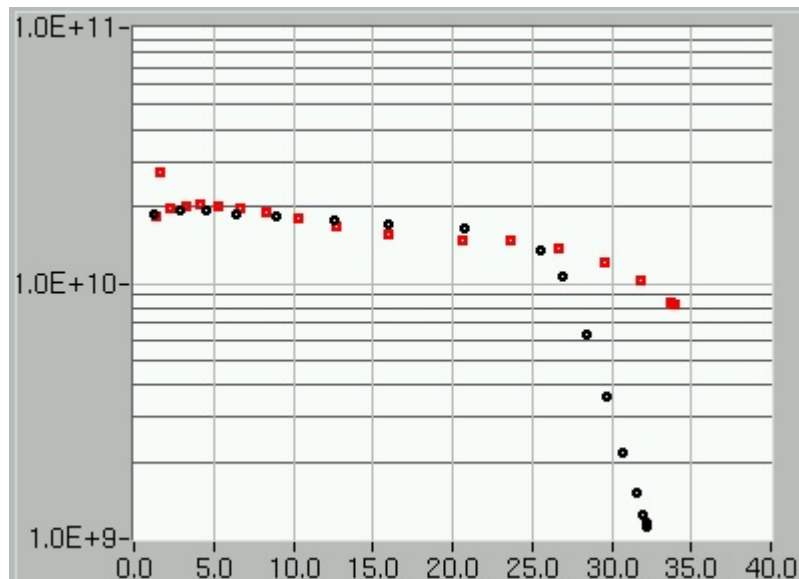
Quench in the equator region

Large grain material: Summary

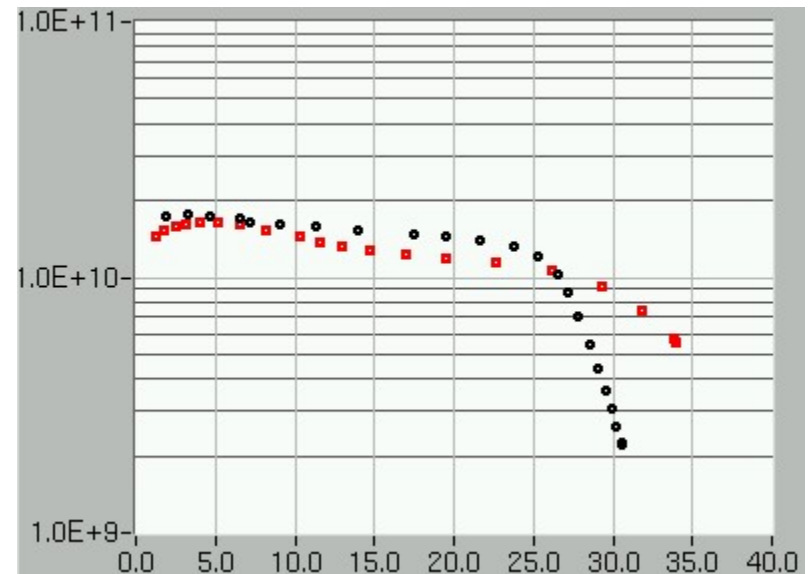
- Electropolished Heraeus “large grain”- niobium gives comparable performance to the best “fine grain”- Nb cavities
- First cavity with spun cups shows significant lower gradient (1 of 1)
- **Q-disease checked on two cavity only**
- Ongoing tests after etching (BCP)
=> 1AC3 lost 12 MV/m after 50µm BCP
 - 2x cavities in two steps; 1x cavity one step
 - new cavity only BCP
- Two more nine-cell cavities ready (Accel Co.)
- Mono-crystal cavity:
 - next test after add. EP
 - poor result compared to P.Kneisel (>38 MV/m in two cavities at 2.3 GHz)
 - second cavity 1AC8 will be send to JLab

Status and Results: Giredmet Nb

- Three cavities fabricated in-house of russian Giredmet Nb with RRR > 600 (2x completed)
- Preparation: 150 μ m EP, 800C firing, 40 μ m EP, HPR, (add. HPR or add. 130C/136C bake)
- Qualification successful !!



Q(E)-curves of 1DE4 before and after bake
(some FE present before and after bake)



Q(E)-curves of 1DE5 before and after bake
(some FE present before and after bake)

Status : Cabot Nb

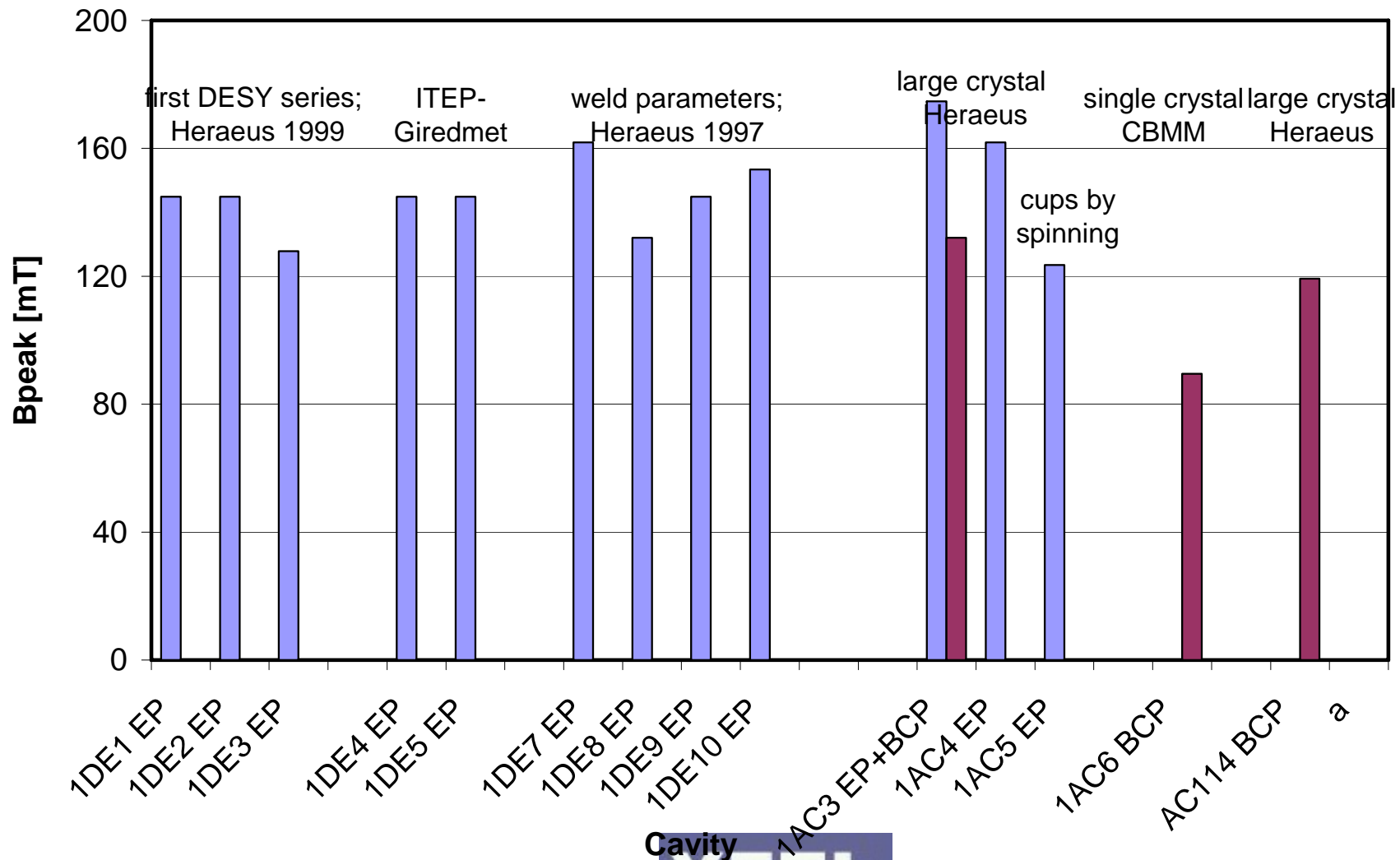
- Two cavities fabricated in-house of Cabot Nb with **RRR ~ 230 !!**
- Preparation: >100µm BCP@Accel, 800C firing, >100µm EP@Henkel, (HPR, 130C bake)
- Tests under preparation

Status : Plansee Nb

- Three cavities fabricated in-house of Heraeus/Plansee Nb with **RRR ~ 300**
- Preparation: >80µm BCP@Accel, 800C firing,
- Further treatment and tests on the way

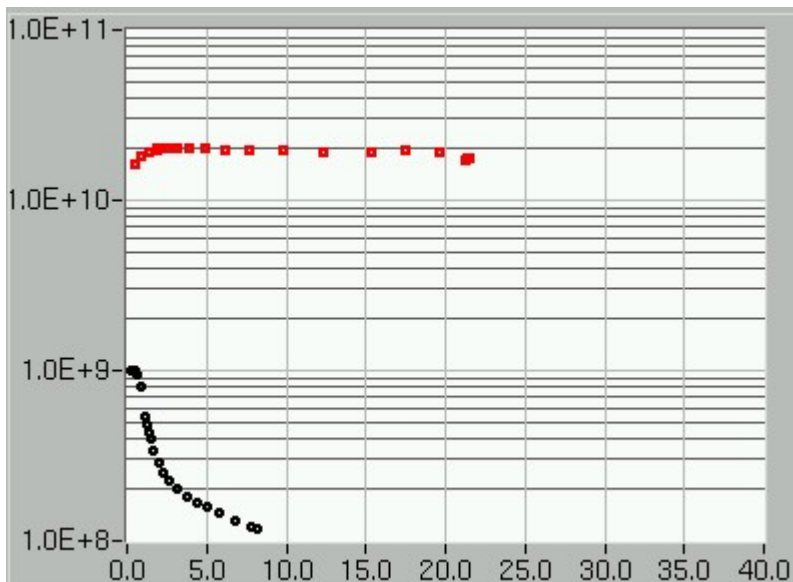
Maximum fields

- Comparison of B_{peak} of DESY fabrication and large grain cavities:



Q-disease

- Q-disease after Henkel EP:
- No Q-disease found after EP at Henkel Co. up to now (not all cavities checked!)
- URGENT: more Q-disease checks of “large grain”-niobium cavities!!!
- Example for Q-disease: mono-crystal cavity after heavy grinding + BCP



1AC6: Q(E)-curves at 2K before
and after 750C + 30µm BCP

Q-disease II

- Q-disease checks of cavities after EP at Henkel Co:
 - 1AC2; no Q-disease at 100K (Jun 03)
 - 1AC2: no Q-disease after 40h at 115 -125K (between tests, april 05)
 - 1AC2: no Q-disease after ??? (Sep 05)
 - 1AC5: no Q-disease after 12h at 120K (Mar 06)
 - 1DE2: no Q-disease after ???
 - 1DE3: no Q-disease after 110K over night (Jan 06)
 - 1DE4: no Q-disease after 18h at 100-120K
 - 1DE9: no Q-disease after 15h at 80 -100 K (Jan 06, between tests)
 - 1DE10: no Q-disease after 75 – 90K over night (Jan 06, before test)

maybe some more

Summary, next steps and some problems

- Qualification of DESY in-house cavity fabrication successful
=> reproducible gradients above 30MV/m
- Modified welding preparation gives good results
=> complete cavity tests for changed welding preparation (“8h-Regel”)
=> application to next single-cells for more statistics
- “Large-grain” show excellent results after EP
=> more tests after BCP of existing “large grain” cavities => lower gradient?
=> ongoing comparison between BCP and EP on “large grain” Nb material
- New EP preparation of mono-crystal cavity 1AC6
1AC8 will be send to JLab for preparation and testing
- Complex behavior of electrolytic bath of the EP process
=> study about electrolyte management starts now (Henkel Co., DESY)
=> 2 single-cells treated with different electrolytes (waiting for final measurement)

Summary, next steps and some problems

- Plansee niobium cavities ready and under preparation
- Ningxia niobium cavities under fabrication
- Fabrication, preparation and test of “large grain” niobium cavities at DESY (autumn 06)
- First “large grain” 9-cell cavity tested; two more ready
- Upcoming presentation:
 - Test and improvement of parameters of dry-ice cleaning
 - Analysis of “120C bake” procedure
- Workflow at DESY needs further optimisation
- Etching and electropolishing facilities at DESY are overloaded with nine-cells

Thanks!

- Thanks to all colleagues for their support:
 - MVP, MVA, MKS, MHF-sl, ZM, V4, AV, Henkel Co. + all others
- Thanks to J. Iversen + W.Singer

Addendum:

- Additional transparencies for explanation!

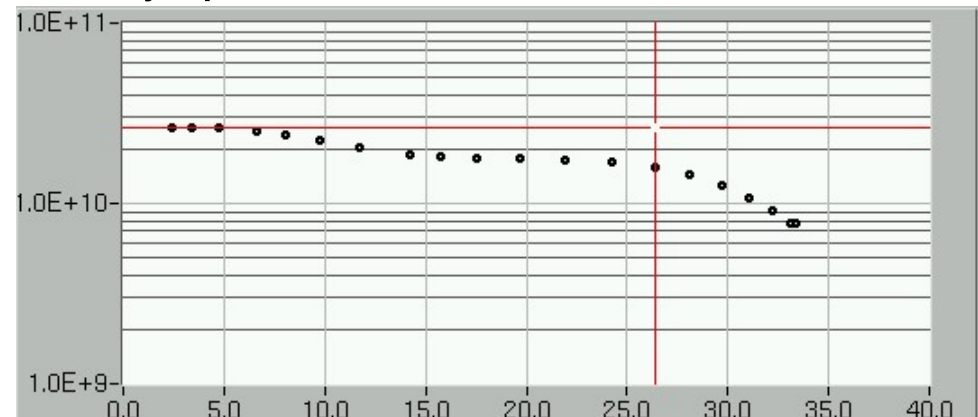
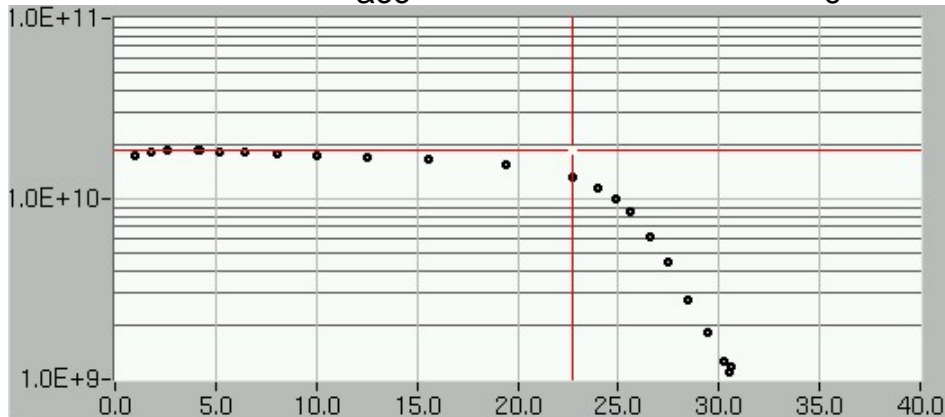
Dry-ice-cleaning

- 1DE4 after 1x HPR + 2x dry-ice cleaning **more FE** (test 3)
- -1DE7 after 2x dry-ice cleaning FE improved (less radiation); low Rres (test 2)
 - add. dry-ice cleaning + **leak during cooldown: more FE**
- 1AC4 after ?x dry-ice cleaning up to 16MV/m no FE; **test stopped due to leak**

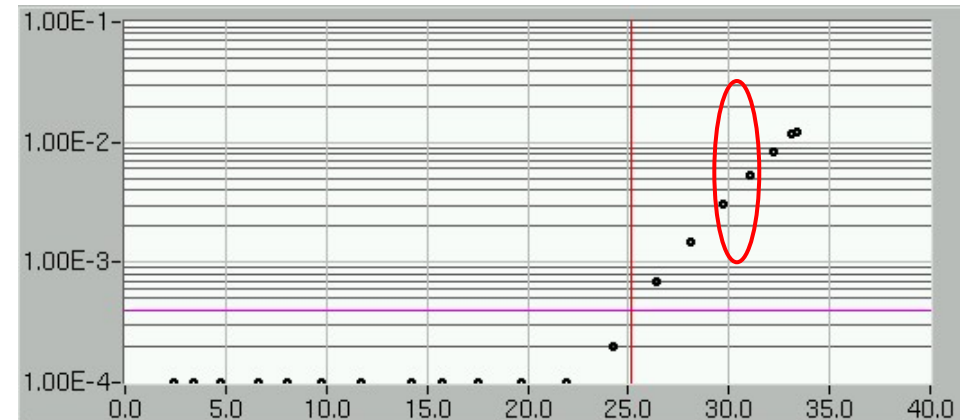
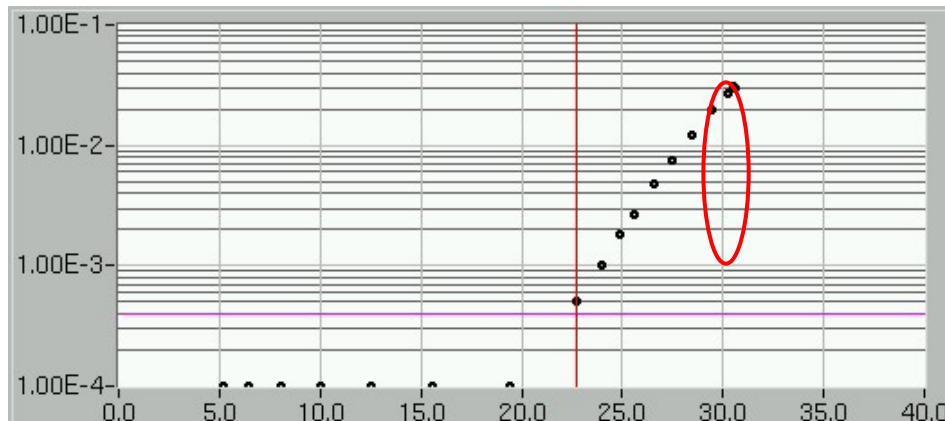
1DE7: improvement after dry-ice cleaning

- Test 2: add. 136°C, 48h bake, 2x **dry-ice cleaning**:

$E_{\text{acc}} = 33,5 \text{ MV/m} @ Q_0 = 8 \cdot 10^9$; lim. by quench; few FE ($>25 / 33 \text{ MV/m}$)



=>

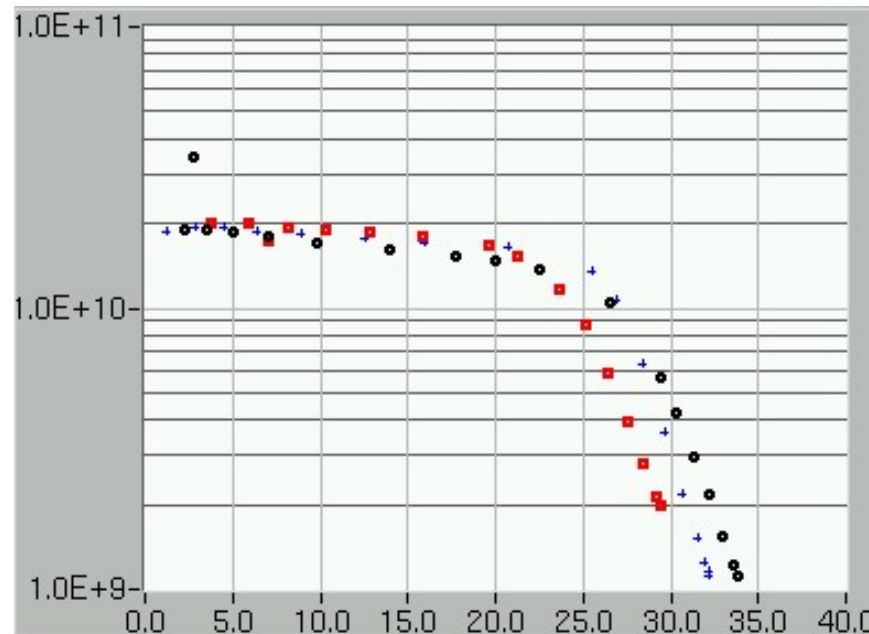


Test 1: $Q(E)$ + x-ray curve at 2K

Test 2: $Q(E)$ + x-ray curve at 2K

1DE4: Summary of first tests II

- Test 2: add. 5x HPR; **check for Q-disease (18h at 100 – 120K)**:
 $E_{\text{acc}} = 34 \text{ MV/m @ } Q_0 = 1,1 \cdot 10^9$; limited by BD; strong **FE** ($>24 / 29 \text{ MV/m}$)
- Test 3: add. 2x dry-ice cleaning
 $E_{\text{acc}} = 29,5 \text{ MV/m @ } Q_0 = 2 \cdot 10^9$; lim. by power + **FE** ($>22 / 26 \text{ MV/m}$); **leak**
- Test 4: add. 3x HPR:
 $E_{\text{acc}} = 32 \text{ MV/m @ } Q_0 = 1,1 \cdot 10^9$; lim. by power; some **FE** ($>25 / 31 \text{ MV/m}$)
(no T-Maps taken)

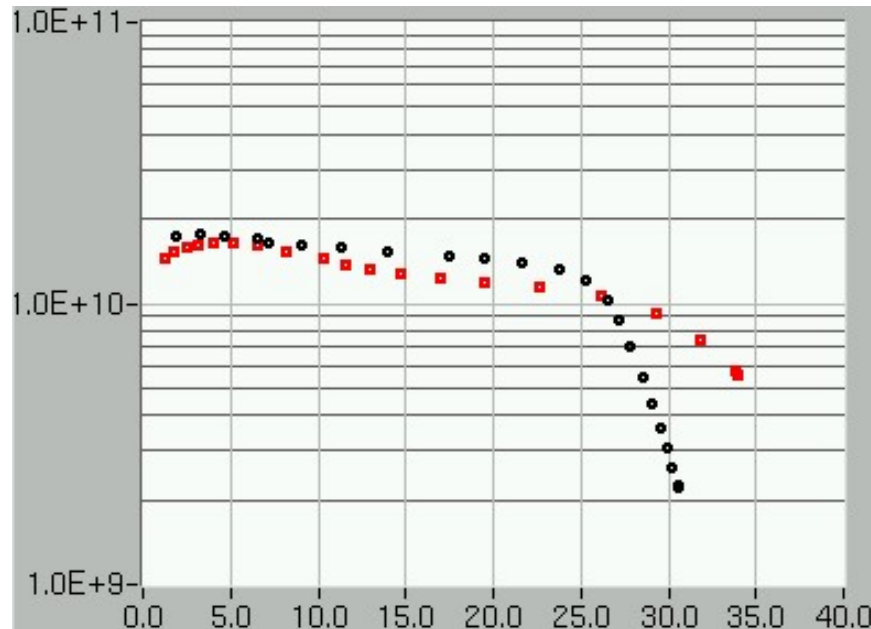


Q(E) - curves at 2K

1DE5: Summary of first tests II

- Test 2: add. bake at 136°C, 48h:

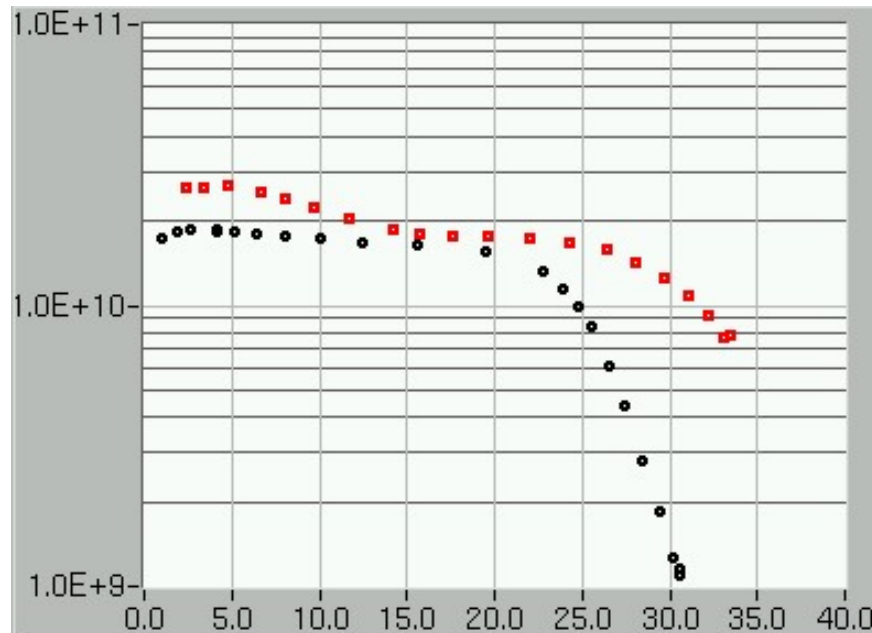
$E_{\text{acc}} = 34 \text{ MV/m} @ Q_0 = 5,5 \cdot 10^9$; limited by BD; some FE ($>28 / 34 \text{ MV/m}$)
(no T-Maps taken)



Q(E) before and after bake; 2K

1DE7: Summary of first tests

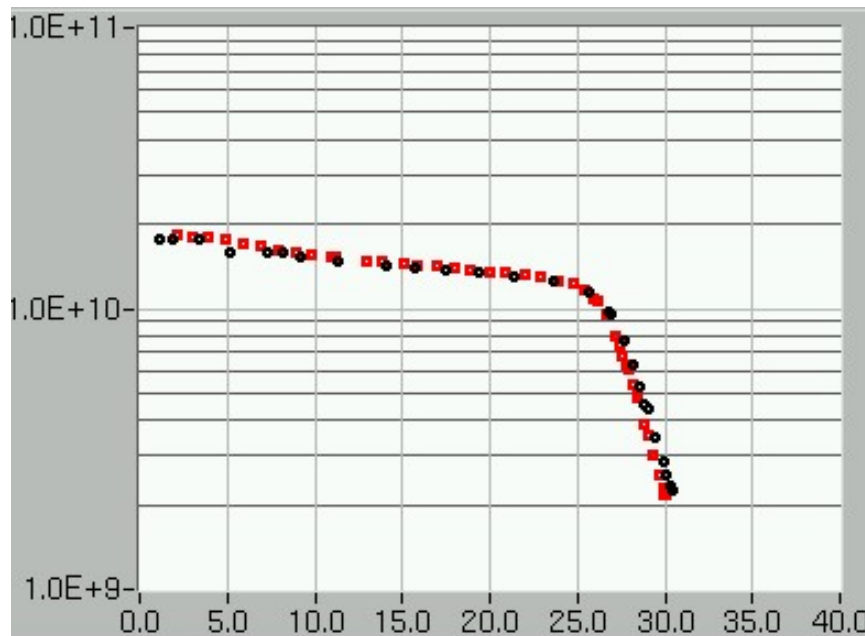
- Nb with RRR 300 (Heraeus); deepdrawing at Zanon Co.; machining + EB welds at DESY
- Reference cavity for improvement of welding parameters
- Test 1: 84 μm BCP@DESY, 800C, 100 μm EP@Henkel, HPR:
 $E_{\text{acc}} = 31 \text{ MV/m}$ @ $Q_0 = 1,4 \cdot 10^9$; lim. by power; some FE (>22 / 28MV/m)
- Test 2: add. 136°C, 48h bake, 2x dry-ice cleaning
 $E_{\text{acc}} = 33,5 \text{ MV/m}$ @ $Q_0 = 8 \cdot 10^9$; lim. by quench; few FE (>25 / 33MV/m)



Q(E) - curves at 2K before and
after bake

1DE9: Summary of first test

- Nb with RRR 300 (Heraeus); deepdrawing at Zanon Co.; machining + EB welds at DESY
- check of welding parameters: storage for 168h under vacuum
- Test 1: 119 μm BCP@DESY, 800C, 100 μm EP@Henkel, HPR:
 $E_{\text{acc}} = 30,4 \text{ MV/m}$ @ $Q_0 = 2,2 \cdot 10^9$; lim. by power; **no FE**
 - no Q-disease after 15h at 80 – 100K



Q(E) - curve at 2K before and
after Q-disease check

1DE9: Summary of first tests II

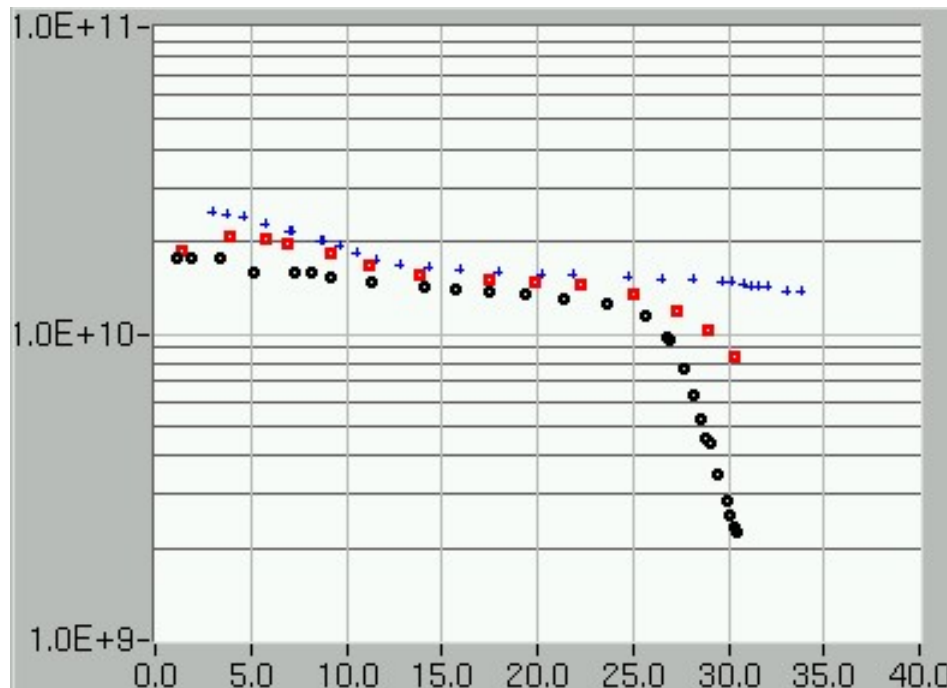
- Test 2: add. bake 138C, 48h:

$$E_{\text{acc}} = 30,4 \text{ MV/m} @ Q_0 = 8,4 \cdot 10^9; \text{ lim. by BD} \Rightarrow \text{FE induced? } (>26 / - \text{ MV/m})$$

(T-maps)

- Test 3: add. 3x HPR:

$$E_{\text{acc}} = 33,8 \text{ MV/m} @ Q_0 = 1,4 \cdot 10^{10}; \text{ lim. by BD; no FE? } (\text{T-Maps})$$



Q(E) - curve at 2K before bake,
after bake and **after add. HPR**

1DE10: Summary of first tests

- Nb with RRR 300 (Heraeus); deepdrawing at Zanon Co.; machining + EB welds at DESY
- check of welding parameters: storage for 168h under nitrogen
- Test 1: 176 μm BCP@DESY, 800C, 100 μm EP@Henkel, HPR:
 $E_{\text{acc}} = 32,5 \text{ MV/m}$ @ $Q_0 = 1,5 \cdot 10^9$; lim. by quench; some FE (>31? / 31MV/m)
(no T-Maps)
- no Q-disease after parking at 90K – 150K over night

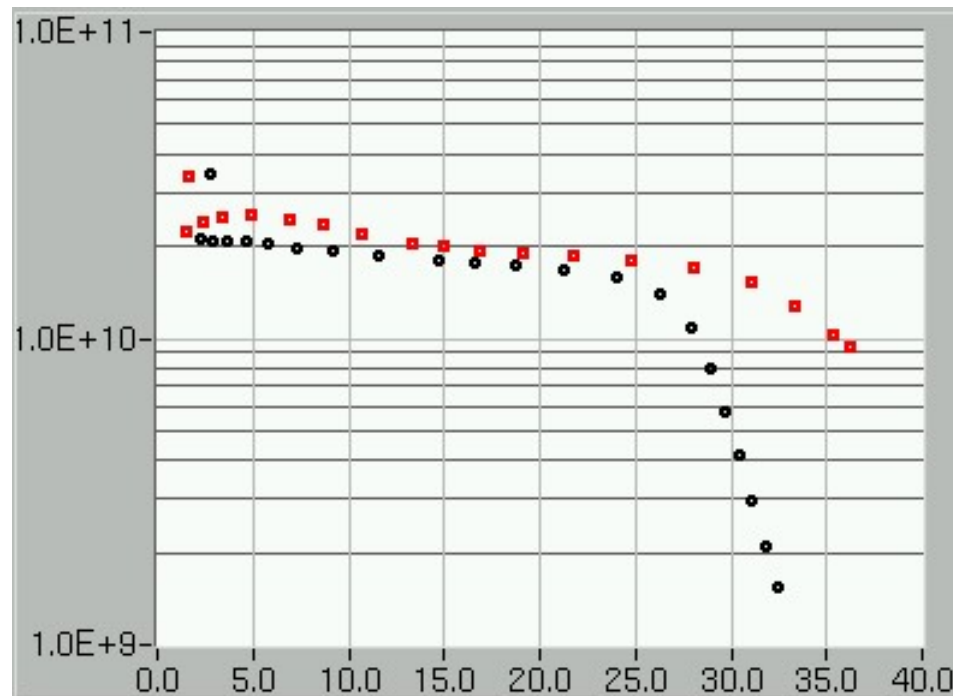
1DE10: Summary of first tests II

- Test 2: add. bake ca. 130C, 48h:

$$E_{\text{acc}} = 36,1 \text{ MV/m} @ Q_0 = 9,4 \cdot 10^9; \text{ lim. by BD; few FE } (>29 / 35 \text{ MV/m})$$

(no T-Maps)

- no Q-disease after parking at 75K – 90K over night



Q(E) - curve at 2K before and **after** bake

Courtesy by Peter Kneisel

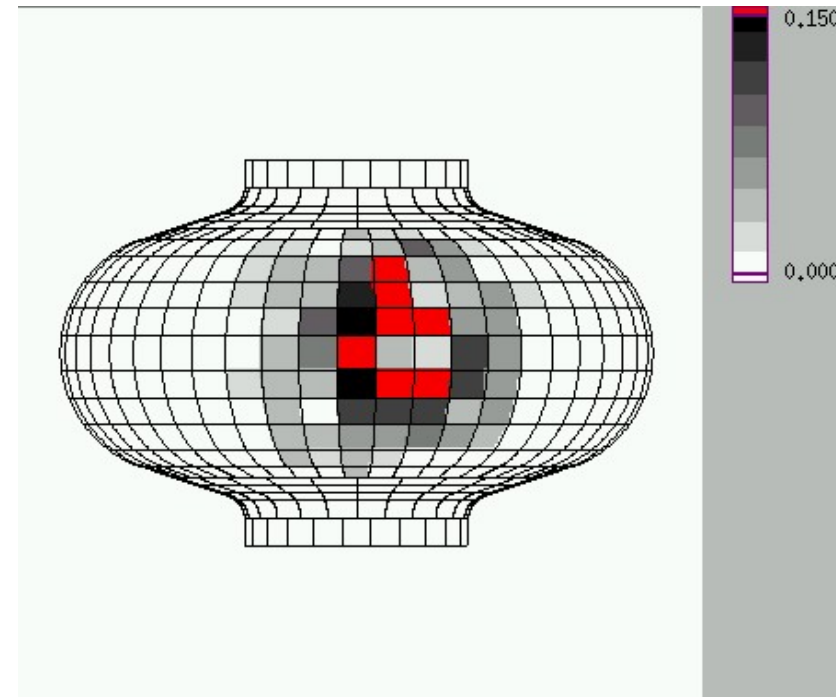
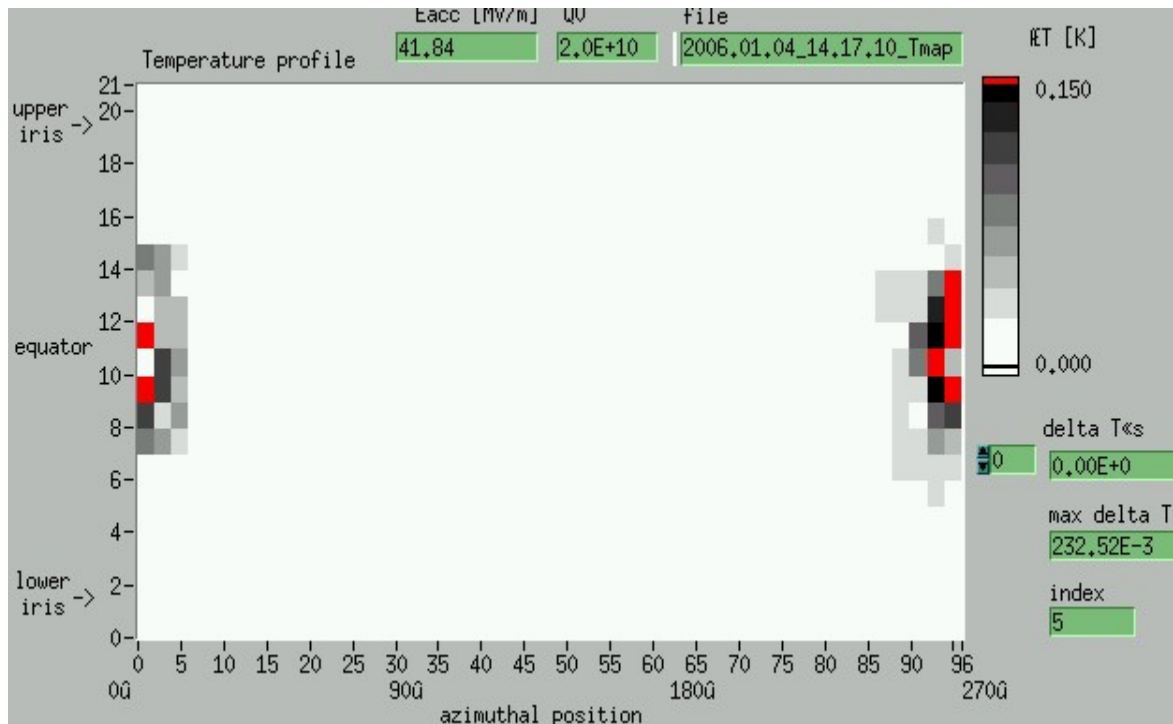
Update since Snowmass(2)

Large grain Ingot "D" from CBMM



1AC3: T-Maps of Test 3

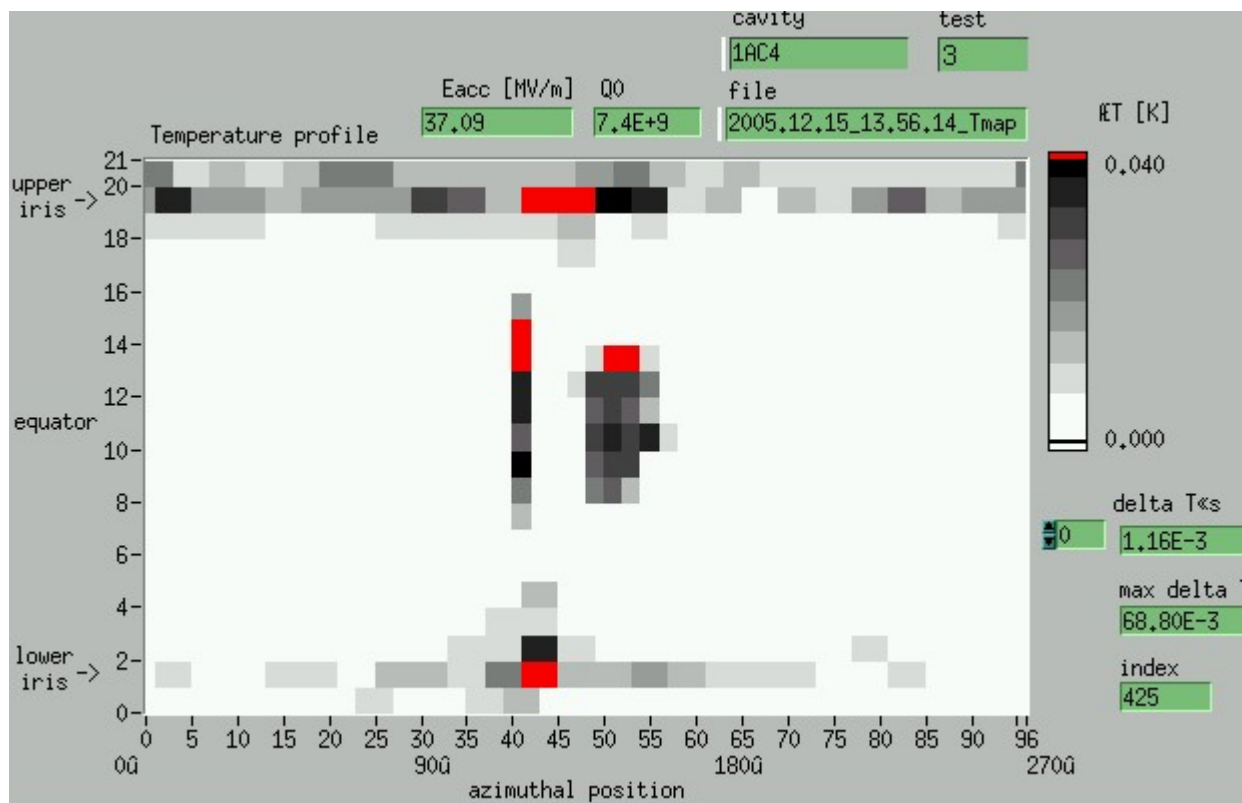
- Test 3: T-Maps at 1.8K **during** quench
 $E_{\text{acc}} = 41 \text{ MV/m}$ @ $Q_0 = 2,0 \cdot 10^{10}$



T-Map at 1.8K

1AC4: History of first tests II

- T-Map no. 10 of test 3 at 37 MV/m:



- quench location around the equator dominating; hot spot off the equator
- trace and hot spots of field emission clearly visible

Quench locations

- Table of quench locations of DESY fabrication and large-grain cavities:

Cavity	Gradient	Quench location	Preparation + remark
1DE1	34	lower cup, close to iris	EP; no FE
1DE2	31	equator area	EP; no FE
1DE3	28	above equator; not clear	EP; no FE
1DE7	33	lower cup; mid equator – iris	EP; probably FE-induced
1DE8	31	equator area; little above	EP; no FE
1DE9	34	lower cup; between equator – iris	EP; no FE(?)
1DE10	35	equator area, little above	EP; nearly no FE
1AC3	41	equator area, little above	EP; no FE
1AC3	29	lower cup, between equator – iris	BCP ; no FE
1AC4	37	equator area	EP; some FE; 30 degree off
1AC5	29	upper cup; mid equator – iris	EP;
1AC6	19	equator area, little below	BCP , no FE
AC114	28	cell2, upper cup, mid equator –iris	BCP , strong FE => FE induced ?