SRF R&D on Q_0 and gradient at DESY

- ILC-HiGrade cavities and monitoring of the EXFEL production
- Optical inspections
- Studies of the cryo-cycling influence on the Q_0
- CBP polishing of Nb cavities
- T-mapping
- New approach for the Second sound quench evaluation

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HELMHOLTZ ASSOCIATION
ilc higrade
SEVENTH FRAMEWORK PROGRAMME
CRISP
Bundesministe für Bildung und Forschung
Alexander von Humboldt Stiftung/Foundation

European ILC-HiGrade programme

24 cavities are added to the ***EXFEL*** order as a part of the ILC-HiGrade program:

- Initially, serve as **quality control (QC)** sample for the ***EXFEL***
  - extracted regularly, ~**one cavity/month: first half of cavities arrived!**
  - after the **normal acceptance test** will be **taken out** of the production flow --> **R&D**

- Delivered with **full treatment** but **no helium tank**
  -> **maximize** the data output from the test

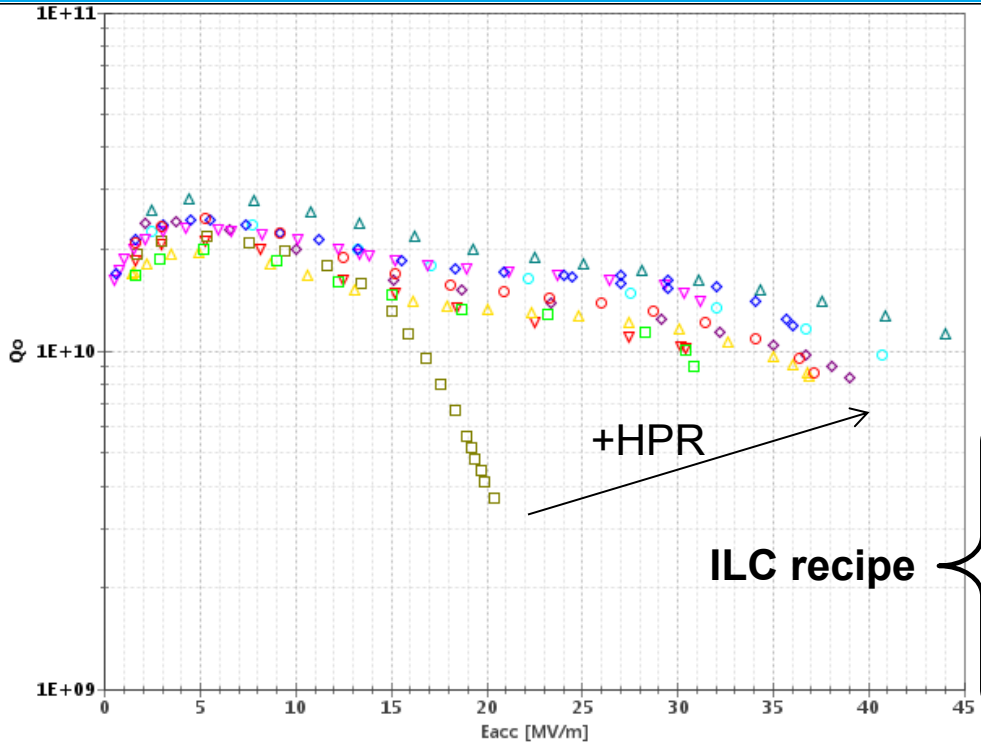
- Further handling within **ILC-HiGrade** **as feasibility study** for **ILC goal**:
  - "Second sound" and T-mapping from the 2nd cold RF test
  - optical inspection (OBACHT) and replica

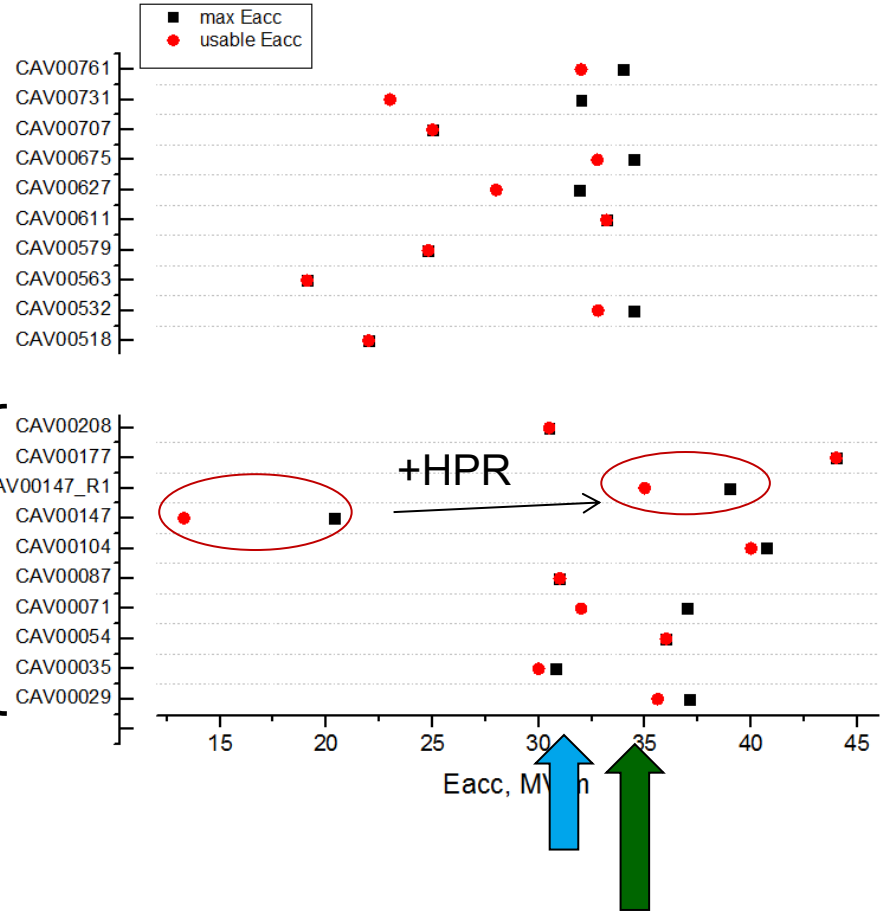
  Further treatment options:
  - Centrifugal Barrel Polishing (CBP)
  - Local Grinding repair
  - additional EP polishing

- Eventually aim **3 world record modules** from the **24 ILC-HiGrade cavities**

20 out of 24 already delivered

Cold rf results of ILC-HiGrade cavities





CAV00029 Test:1.2 AMTF 09/09/13 2[K] bd
CAV00035 Test:1.2 AMTF 09/09/13 2[K] bd_fe
CAV00054 Test:1.2 Hall 3 24/09/13 2[K] bd
CAV00071 Test:1.2 Hall 3 24/10/13 2[K] none
CAV00087 Test:1.2 Hall 3 18/11/13 2[K] bd
CAV00104 Test:1.2 AMTF 04/12/13 2[K] pwr_fe
CAV00147 Test:1.2 AMTF 03/04/14 2[K] bd_fe
CAV00147 Test:2.1 AMTF 28/05/14 2[K] pwr
CAV00177 Test:1.1 AMTF 10/06/14 2[K] pwr
CAV00208 Test:1.1 AMTF 01/09/14 2[K] bd

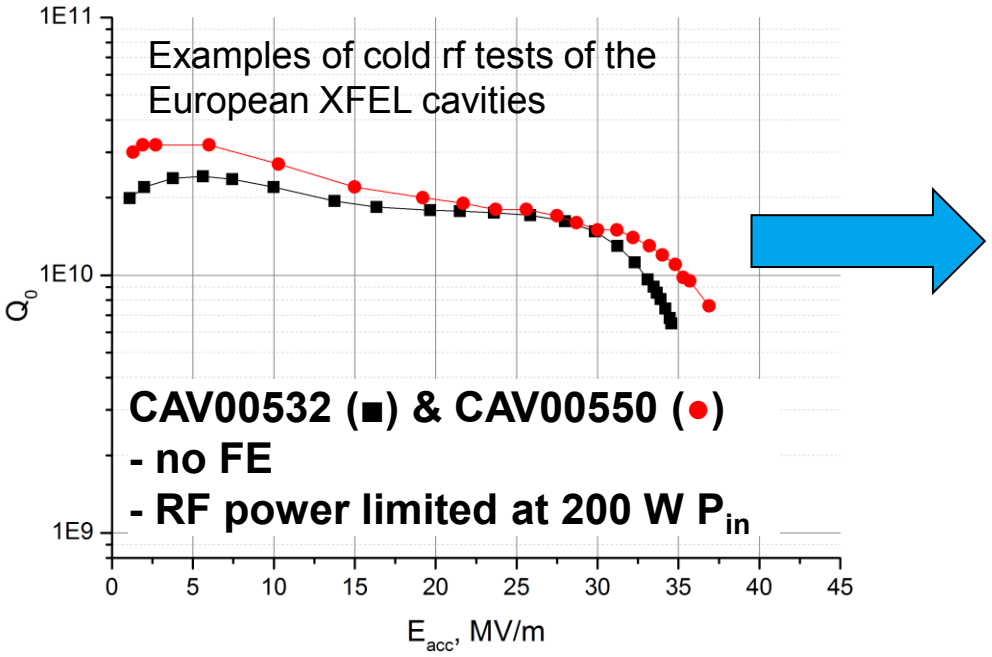
- "ILC recipe" provides cavities with maximum usable gradient of **~31.9±8.2** MV/m and **34.9±4.7 MV/m after retreatment**
- some achieve >40 MV/m

- Main limitation is FE

Monitoring of the EXFEL production

- Solid understanding/control of the industrial mass-production process (with 800 EXFEL +24 ILC-HiGrade cavities)

- Clear **identification** of the **gradient limiting factors**
- **Elaboration** of cavity treatment providing at least **E_{acc} > 35 MV/m** @ **>90% yield**



The EXFEL production process has **provided** cavities with **35 MV/m** gradient

Goal:

- establish **high yield** at high field
- Improve further the **quality control** to reduce the **retreatment** rate

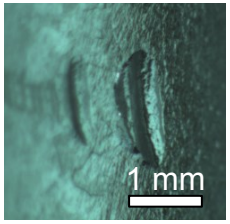
Progress in quality assurance for industrial cavity production

OBACHT (for **optical scan of inner cavity surface**) is in routine and successful operation for all ILC-HiGrade and suspicious EXFEL cavities

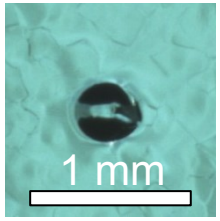
- **Quality control (-> correct QA scheme is an essential issue)**
- **Valuable** feedback to the production
- Failure reason **clarification**

Examples of defects:

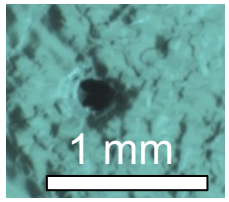
Scratches



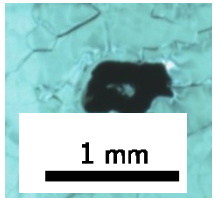
"Cat eyes"



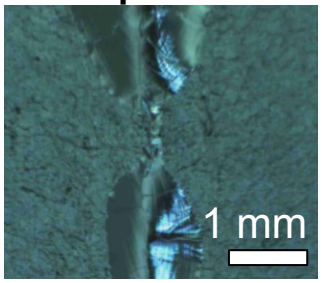
Pits



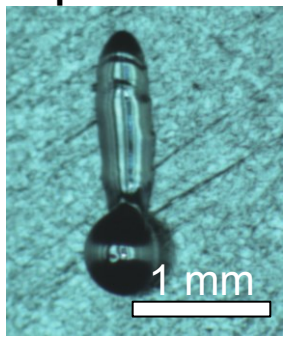
Inclusions



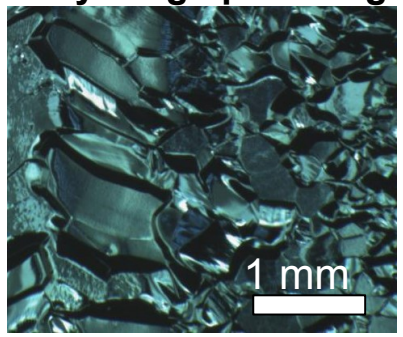
Incomplete weld

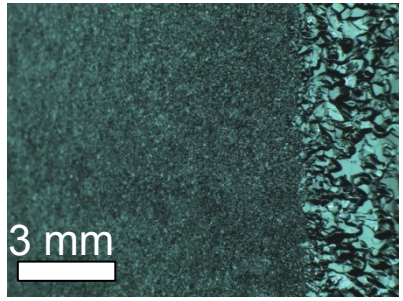


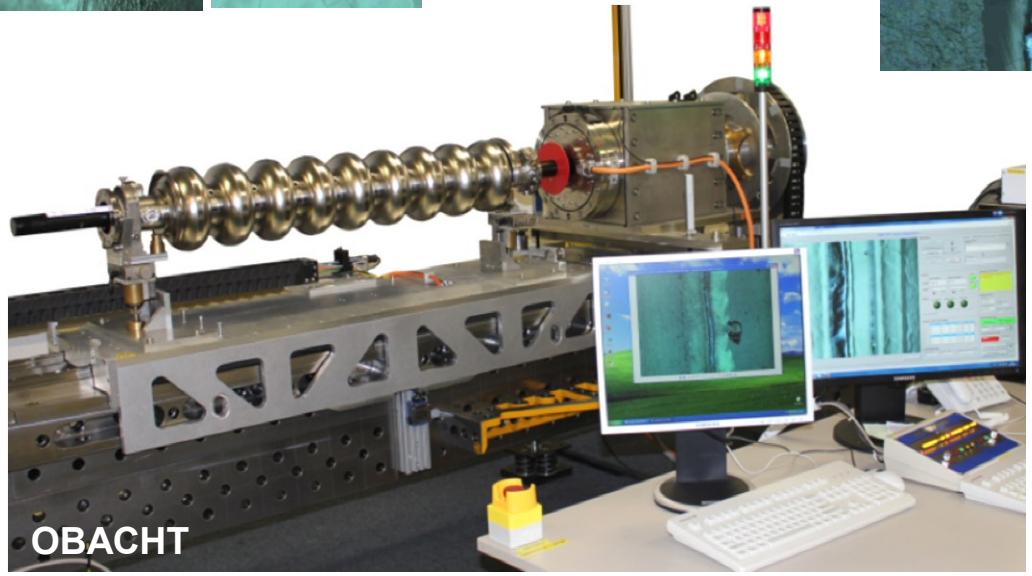
"Spatters"



"Very rough polishing"







Progress in quality assurance for industrial cavity production

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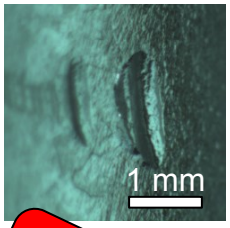
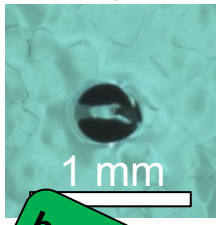
Examples of defects:

Scratches



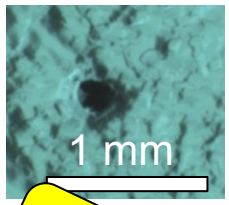
still an issue

"Cat eyes"



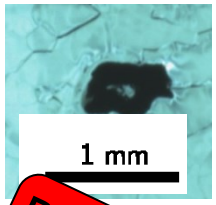
harmless

Pits



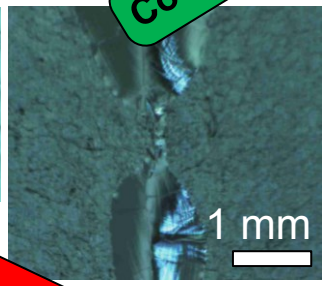
???

Inclusions



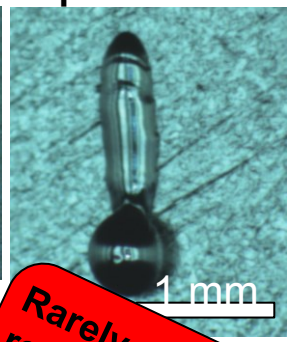
Rarely, still an issue

Incom veld



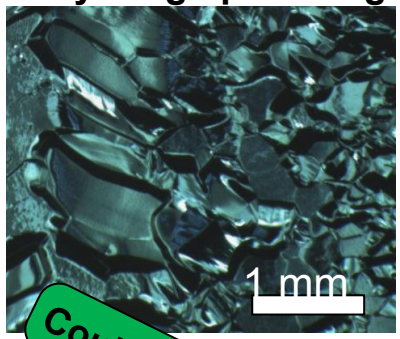
Could be rules out

"Spatters"

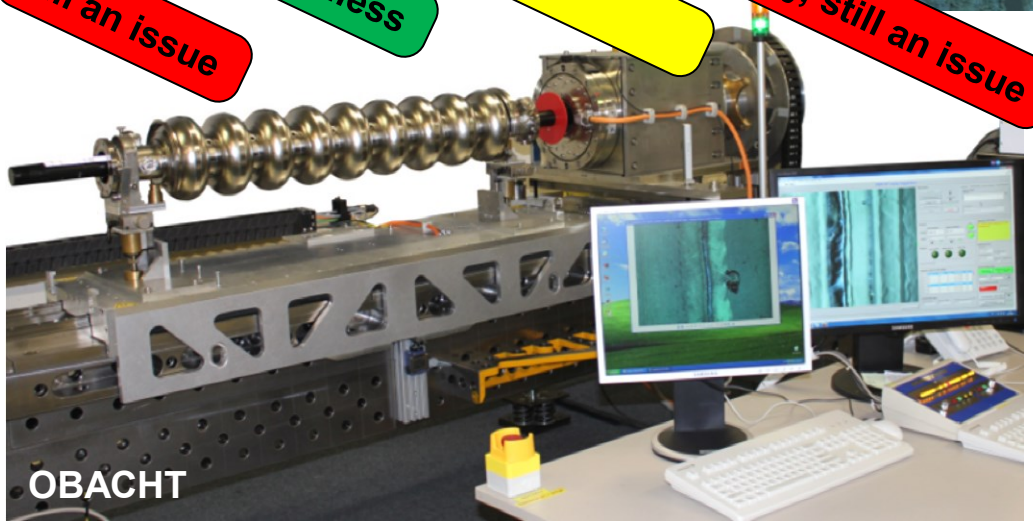


Rarely, still an issue, repair required

"Very rough polishing"



Could be rules out

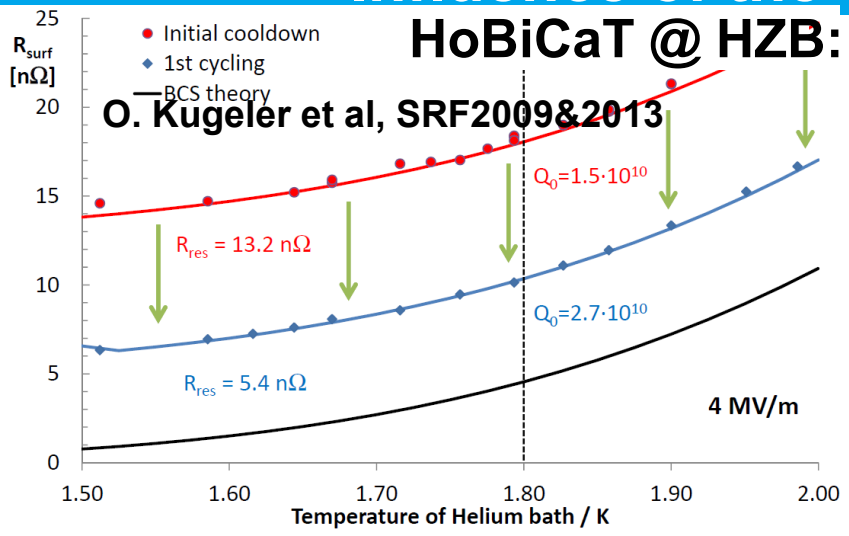


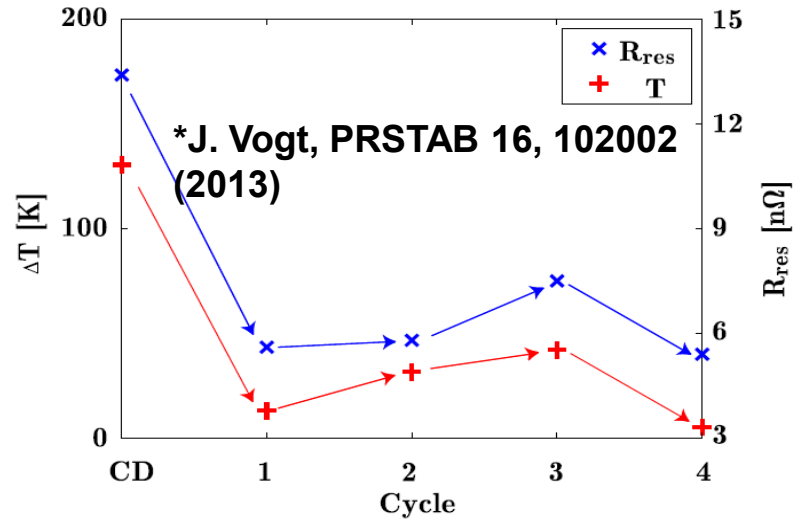
⇒ Similar system/QC at the companies would **reduce significantly re-tests** and **re-treatments** by earlier detection

⇒ The actual system is to be **speedup** at least factor 3-4 and automated to be production-friendly

Influence of the cooling dynamics on Q0

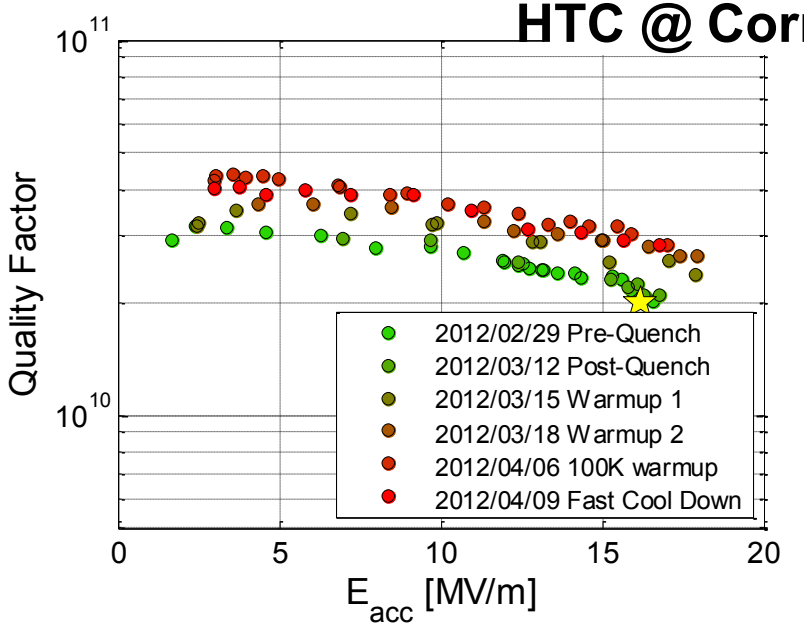
HoBiCaT @ HZB:





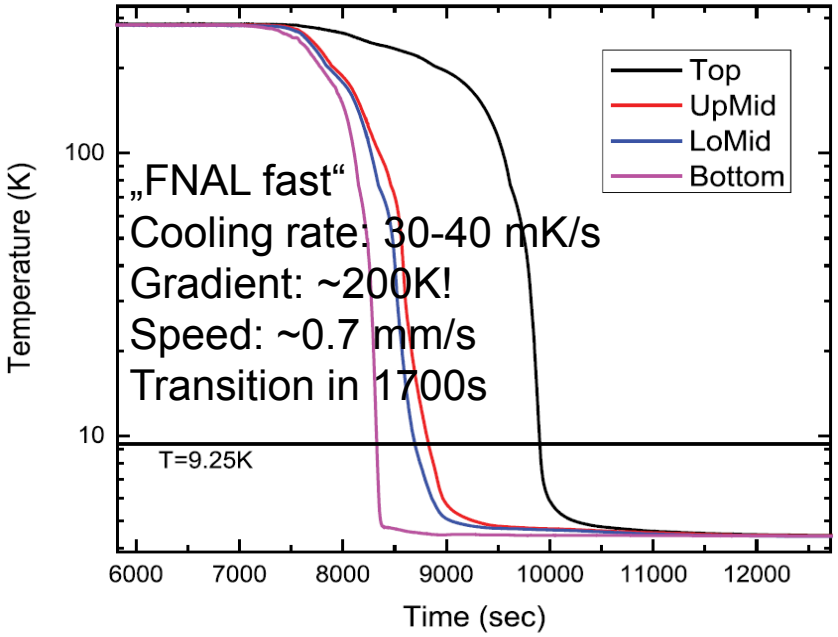
⇒ **At least factor 2.5 gain in Q0**
⇒ Effect at cycle briefly above Tc
⇒ Isothermal slow cooling required
⇒ Expulsion of trapped flux is responsible
(+*S. Aull, SRF2013)

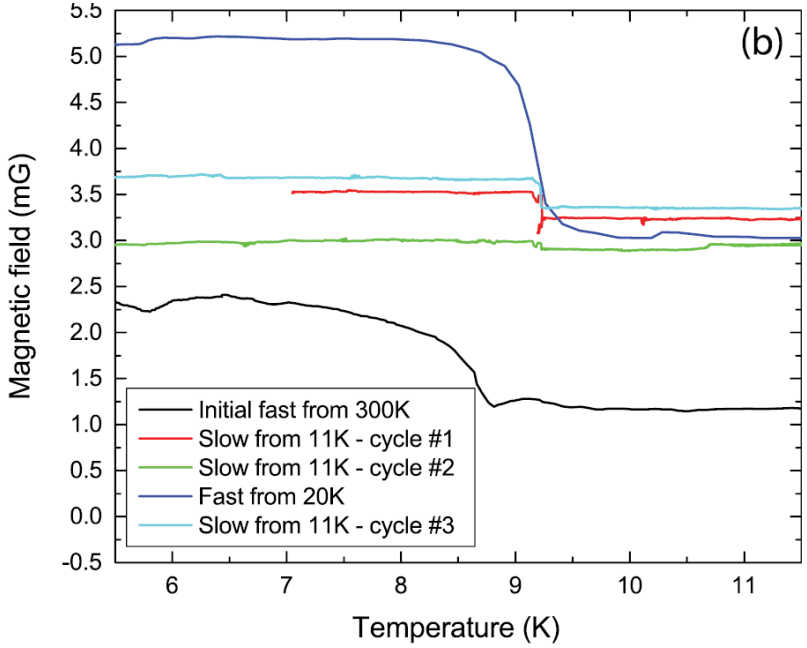
HTC @ Cornell:

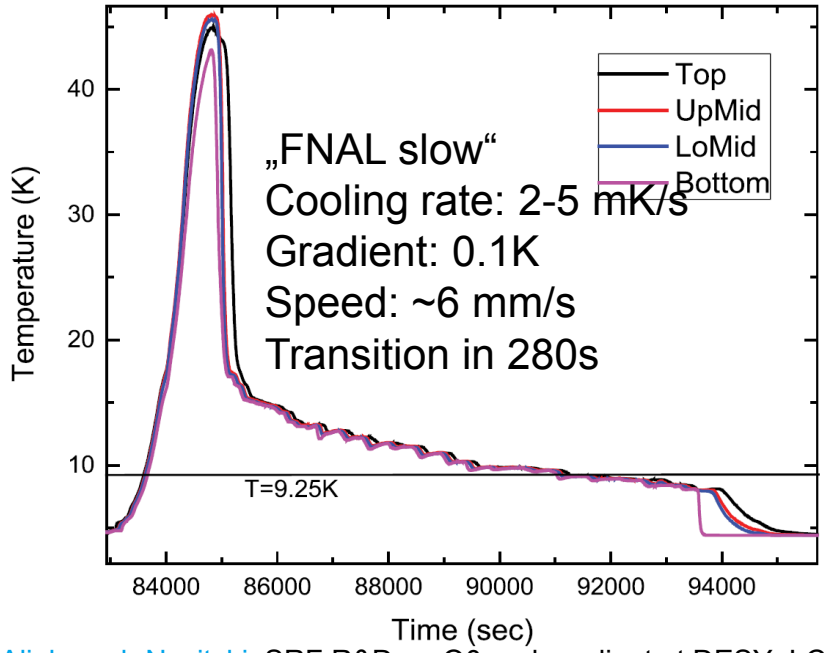


⇒ **At least 20-50% gain in Q0**
⇒ Almost same effect for 300, 100, 15 K cycles
⇒ No effect from cycling <9K
⇒ Slow cooling rate (0.1mK/s) and low T gradient (<0.2K) required for high Q0
⇒ Magnetic shielding is essential
****N. Valles, TTC CW_SRF2013***

Influence of the cooling dynamics on Q0







⇒ Significant Q0 increase (at least 50%) observed independent on surface treatment

⇒ Fast cooldown is better than slow

⇒ Cooling rate >30 mK/s is required for passing the Tc (given only for midle of CAV)

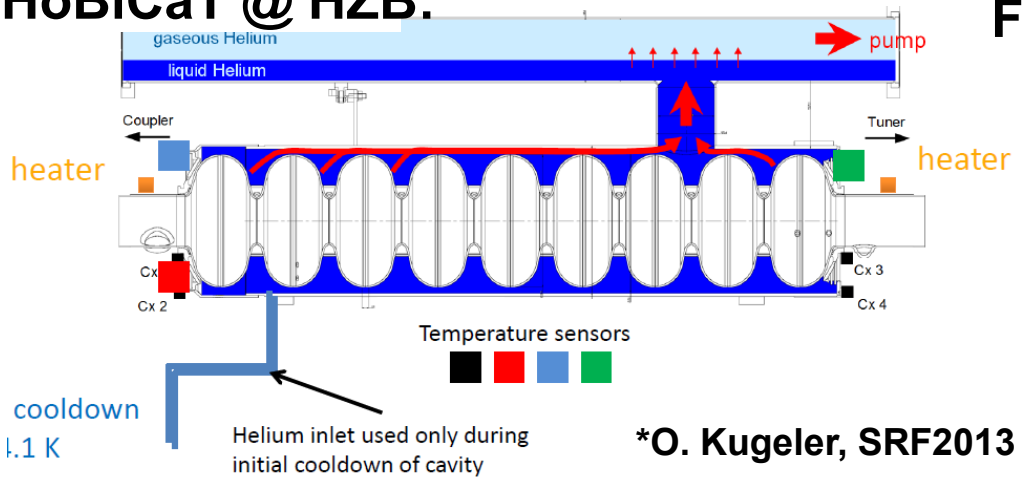
⇒ Flux trapping efficiency is the main effect

⇒ Thermocurrents were excluded since the cavity is insulated!

*A. Romanenko et al., JAP 115, 184903 (2014)

Different schematic of the He filling and of the cooling

HoBiCaT @ HZB:



*O. Kugeler, SRF2013

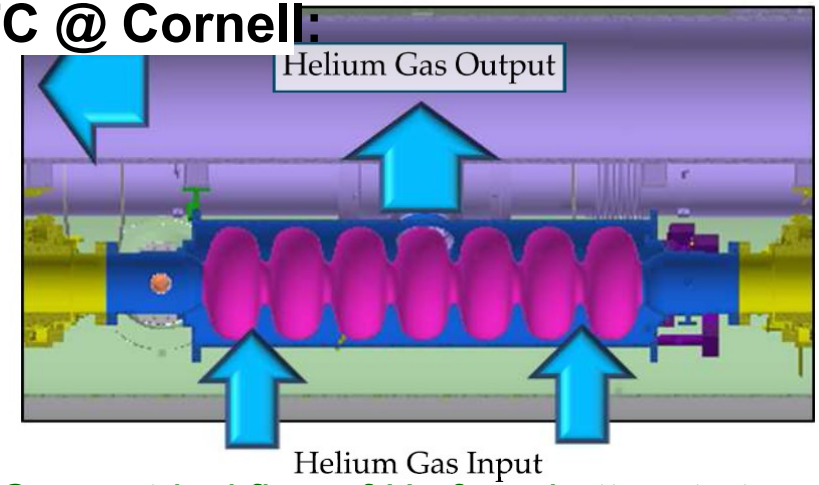
⇒ *Asymmetrical flow of He from one to other side;*
⇒ *Large gradient over the cavity axes and across*
⇒ *Temperature measured on the tank left and right*

Fermilab and DESY:

He flow

⇒ *Flow of He from bottom to top;*
⇒ *Large gradient over the cavity axes;*
⇒ *Temperature measured at different points*

HTC @ Cornell:



⇒ *Symmetrical flow of He from bottom to top;*
⇒ *Gradient over the cavity axes!?*

*N. Valles, PhD Thesis 2014, Cornell University

⇒ ***Difficult to compare oranges with apples***
⇒ ***"FNAL"/"DESY" comparison appropriate despite of insulated cavity at FNAL***

First cooldowns and thermal cycles at DESY

- Q_0 increase observed on cavities w/o Ti tank
- >10% Q_0 increase for both "**slow**" and "**fast**" cooling rates

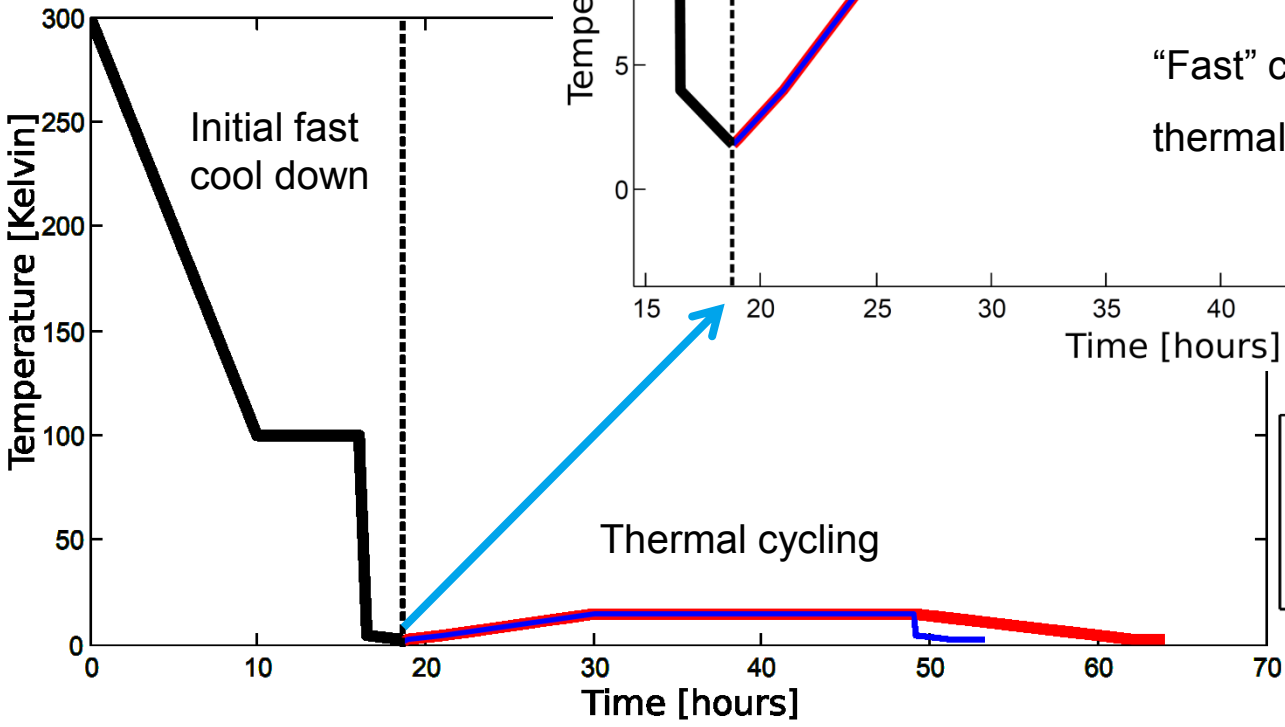
  -> better definition of "fast" or "slow" is required

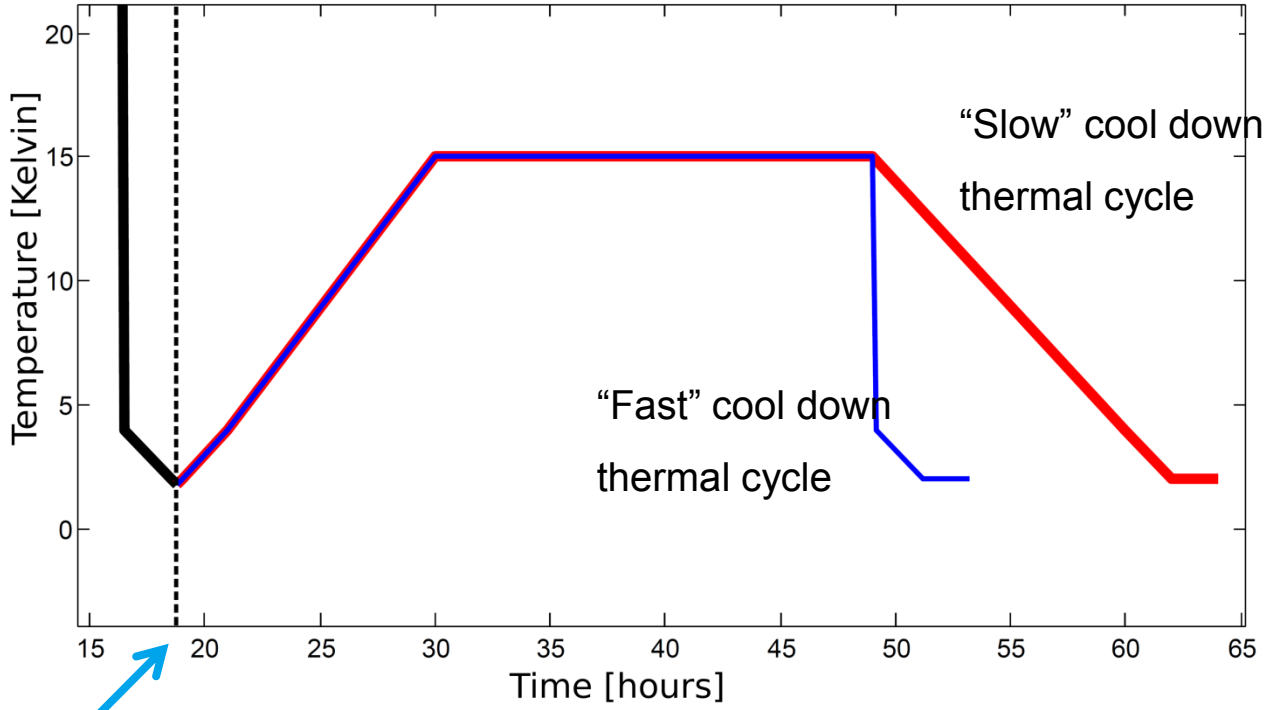
  -> does **T gradient** across the cavity and/or **duration** of the gradient matter rather than **cooling rate**? "Long" processing should favor better flux mobility and expulsion
- The cycling procedure should be feasible for the cryomodules

→ More **precise T control** and measurement of **T profile** required for better understanding

Cooldowns and thermal cycles

- Initial fast cool down (fast „DESY standard“):
- From 300K slow to 100K
- At 100K for 6h (Q-disease)
- From 100K fast to 4K (~30mi
- Pumping to 2K (~ 2h)
-





Initial fast cool down
Slow Thermal Cycle
Fast Thermal Cycle

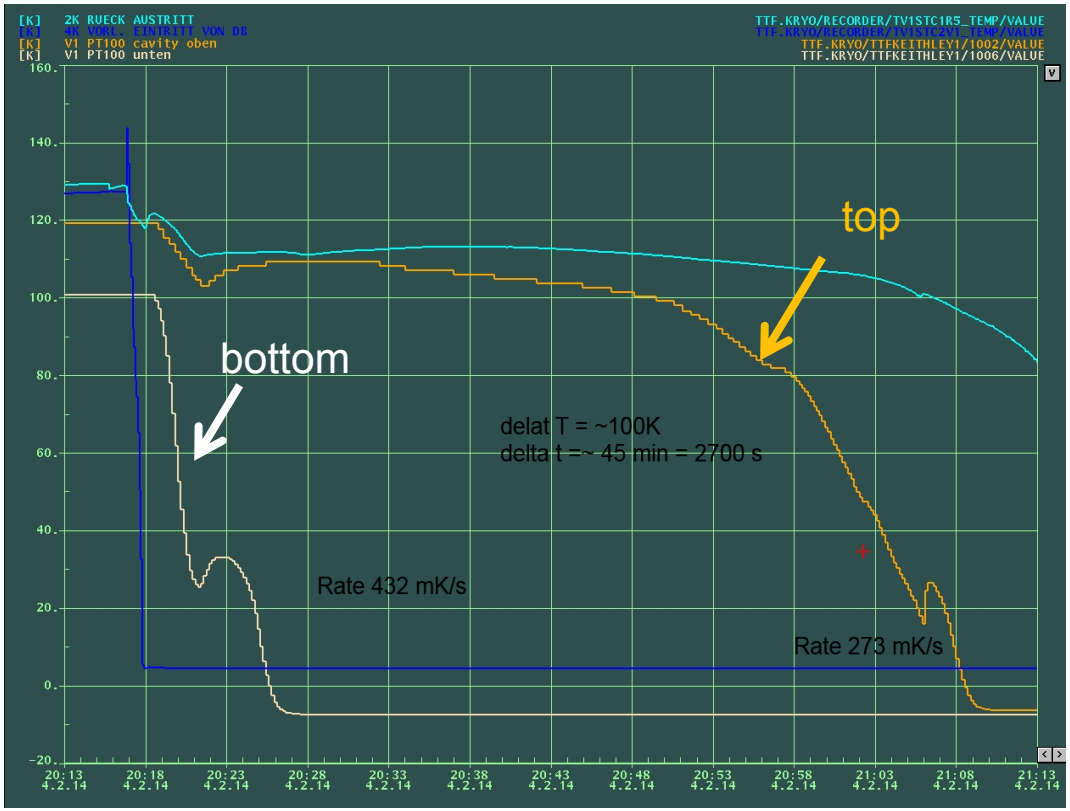
* courtesy of R. Laasch

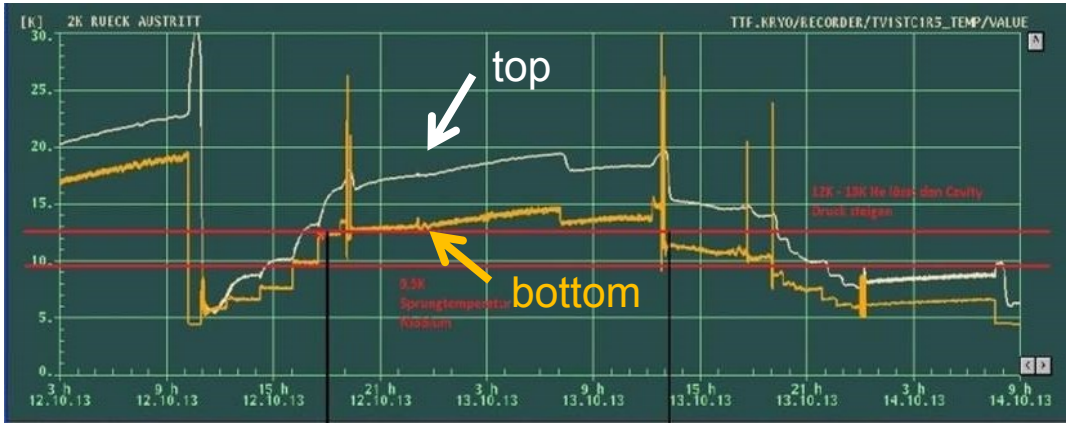
First cooldowns and thermal cycles

„Standard DESY“ cooldown:
Cooling rate across T_c: **273 – 432 *mK/s***
T gradient (at first transition): ***~100 K***
NC-SC border moves up with ~ **0.5 *mm/s***
NC-SC border crosses cavity in **2700 *s***
T gradients across NC-SC border:
~ 80 mK/mm

“Slow DESY” cycling:
Cooling rate across T_c: **< 1 *mK/s***
T gradient (at first transition): ***few K***
NC-SC border moves up **~ 0.1 *mm/s***
NC-SC border crosses cavity in **11520 *s***
T gradients across NC-SC border:
~ 3 mK/mm

“Fast DESY” cycling:
Cooling rate across T_c: **>100 *mK/s***
T gradient (at first transition): ***few K***
NC-SC border moves **up 10-100 *mm/s or***
(cavity cooled almost simultaneously)
NC-SC border crosses cavity in **200 (9) s**
T gradients: ***~ 2-30 mK/mm or***
(no single gradient border)



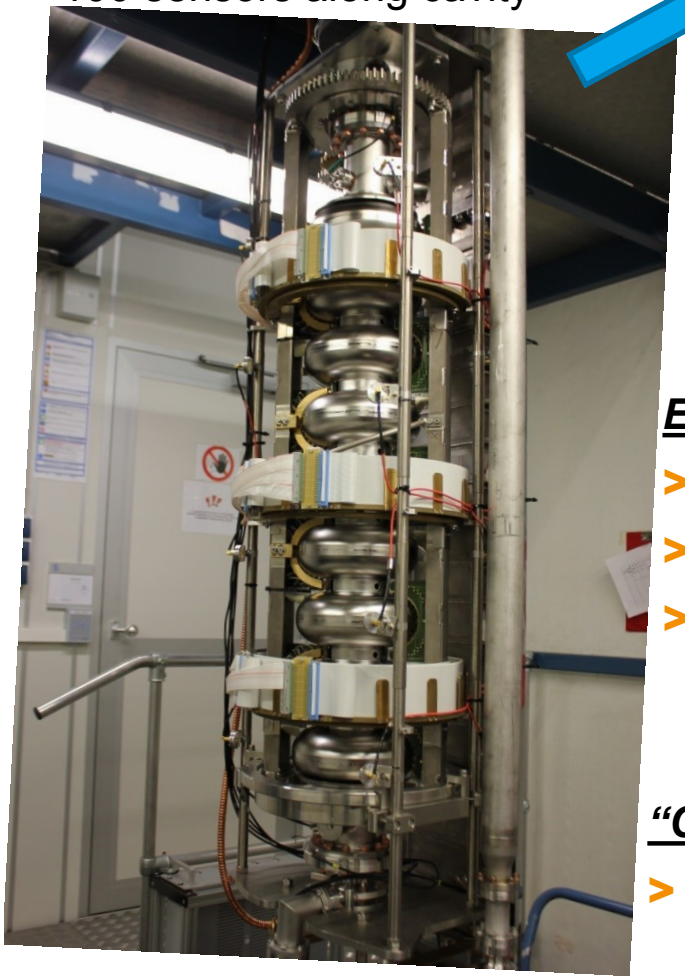


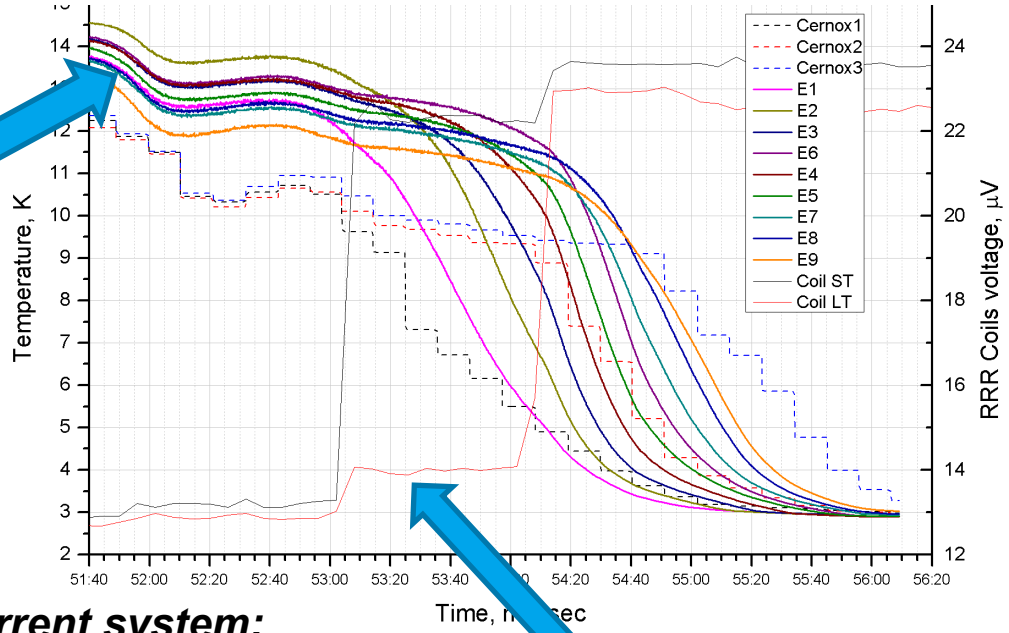
* courtesy of J. Eschke and Y. Tamashevich

Way to better T measurement & control

The new "**T-Mapping**" system at DESY is commissioned:

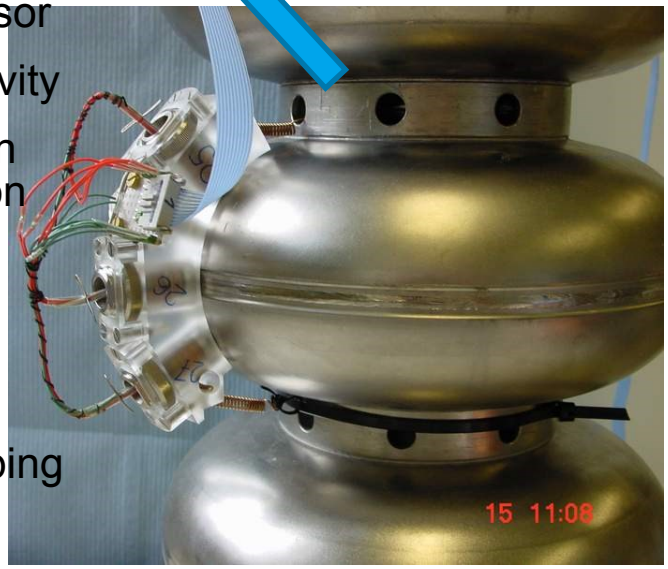
- kHz readout per sensor
- > 100 sensors along cavity





***Eddy-current system*:**

- few Hz readout per sensor
- 9 (27) sensors along cavity
- precise Tc determination and T sensors calibration

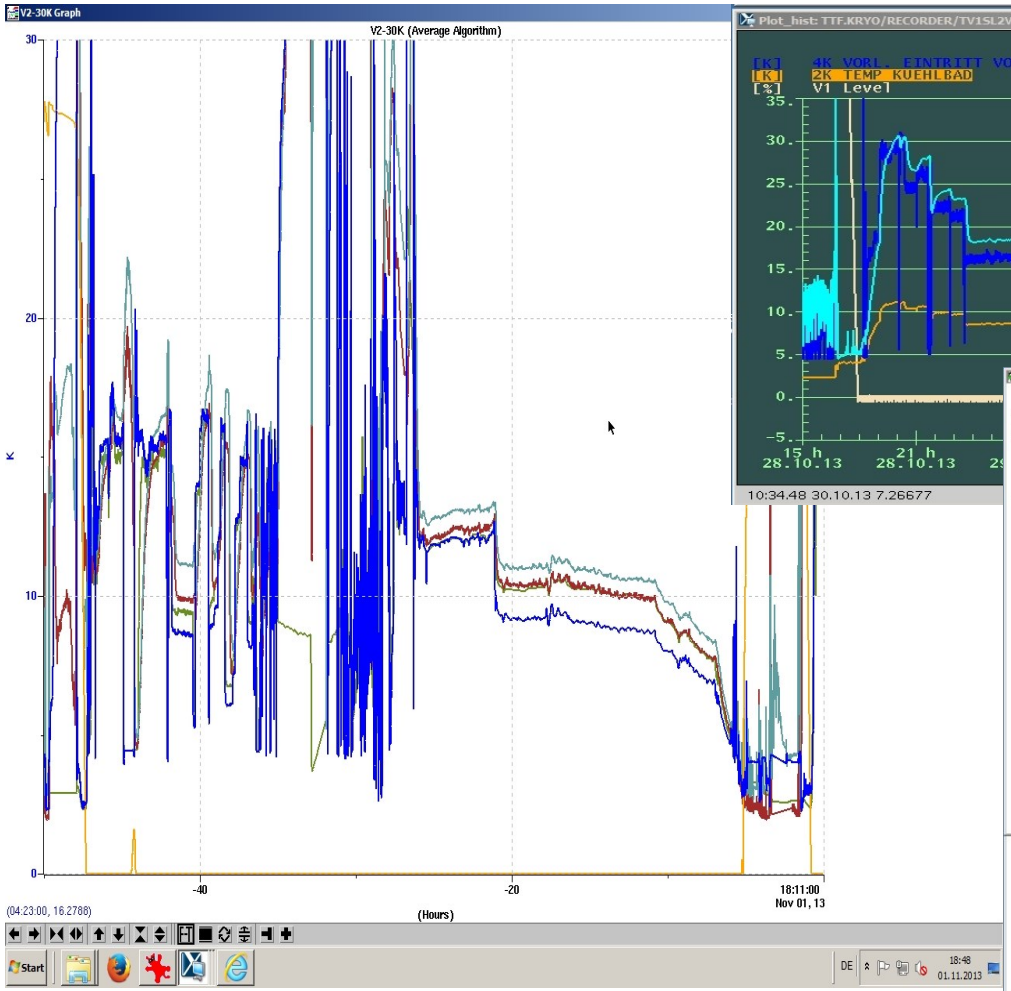


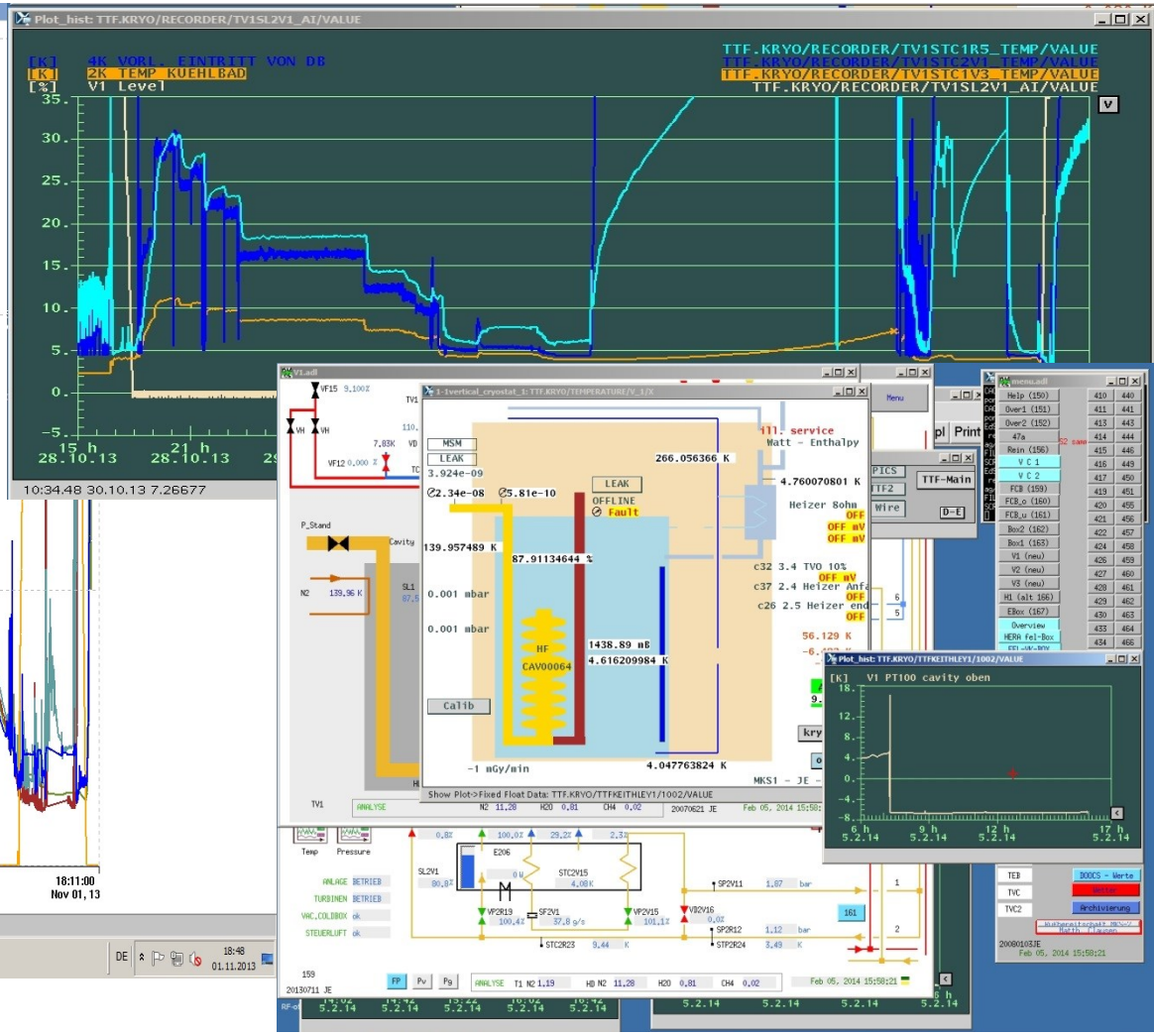
***"Cernox" T sensors*:**

- additional T control and calibration of the T-mapping

Way to better T control:

- **Accurate control, adjustment, and understanding of the cryogenic dynamic require:**





- Many try-outs
- Feedback from the technic showed before is essential

* courtesy of J. Eschke

First results with the “new” technic: Fast “bottom” cooldow

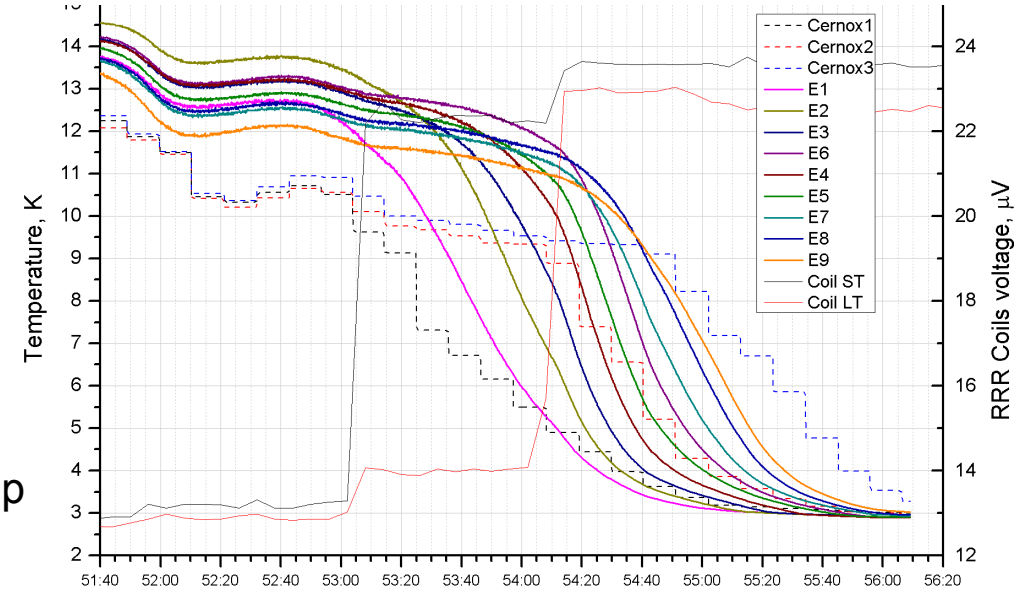
Normal type of cool-down from *14 K* to *3 K*
Cooling rate across T_c: *120-210 mK/s*

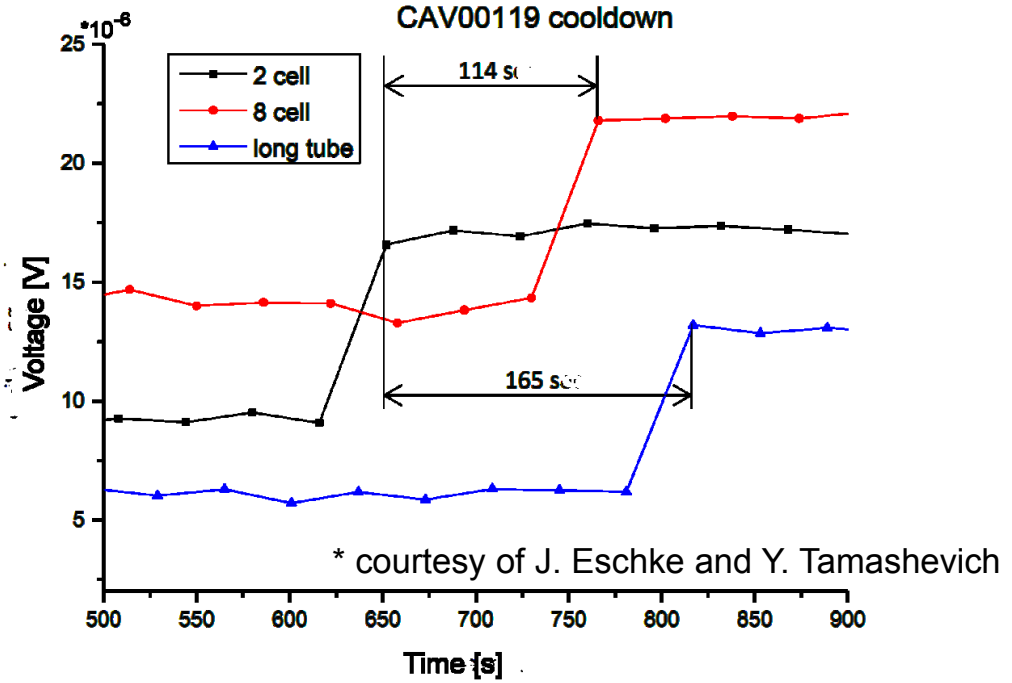
T gradient (at first transition): ~3.5 K

NC-SC border moves from bottom (*E1*) to top (*E9*) with speed starting from *6 mm/s* for *E1* and accelerating up to *100 mm/s* for *E9.*

NC-SC border crosses the cavity in *65 -20*

Temperature gradients across NC-SC bord
24 mK/mm for *E1*
2 mK/mm for *E9*





Expansive cooldown

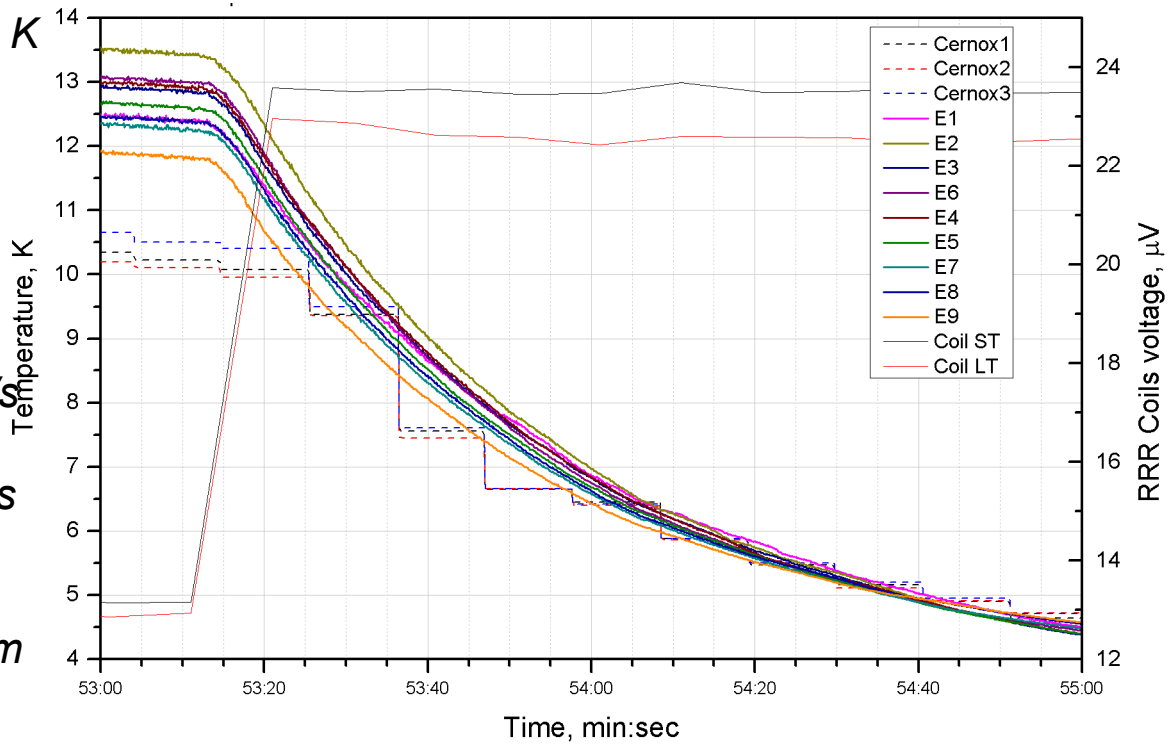
Expansive cool-down from *14 K* to *4.2 K*
Cooling rate across T_c: *110-140 mK/s*

T gradient (at first transition): ~1.2 K

No single NC-SC border.
Different parts of the cavity cross T_c simultaneously, on average ~100 *mm/s*

Whole cavity crosses the T_c in *9 s (less then 3 s in other tests).*

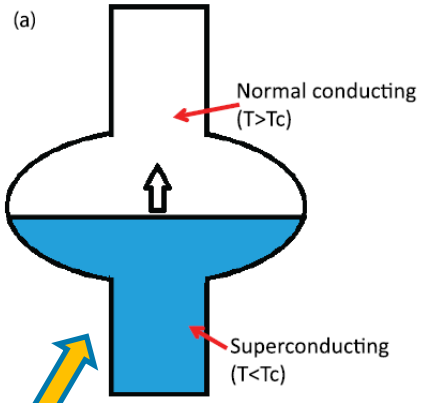
Temperature gradients from *~0 mK/mm* to *4 mK/mm.*

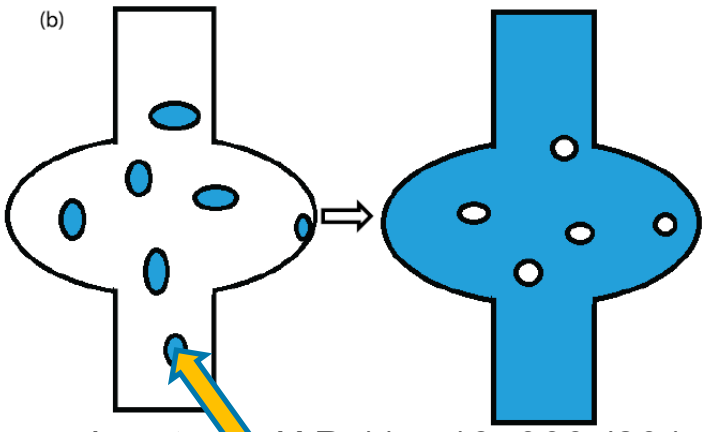


* courtesy of J. Eschke and Y. Tamashevich

Reason for the better flux expulsion:

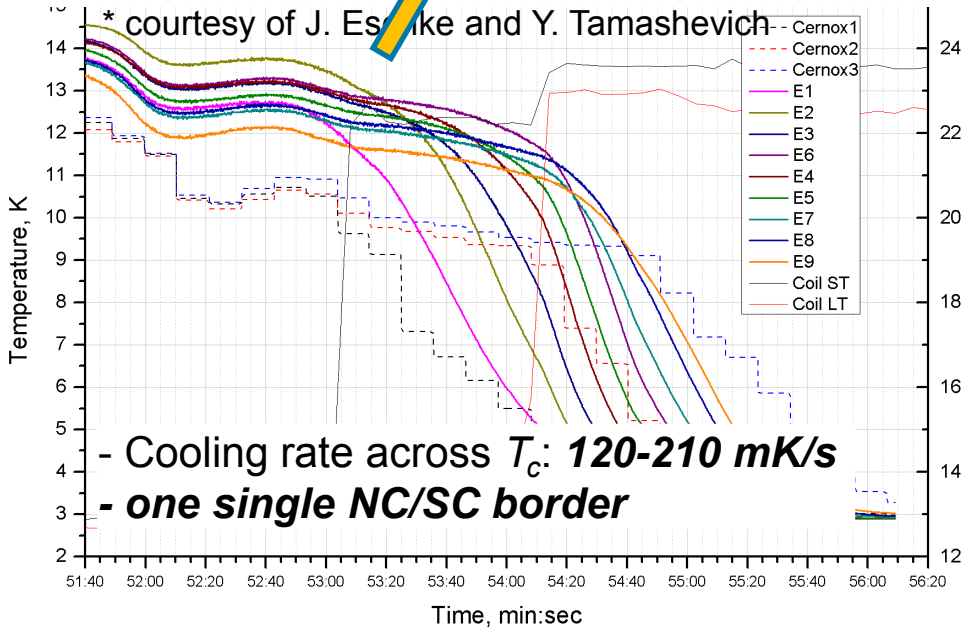
Sweep of NC/SC border at „**fast**“ cooling rate
-> **better** flux expulsion

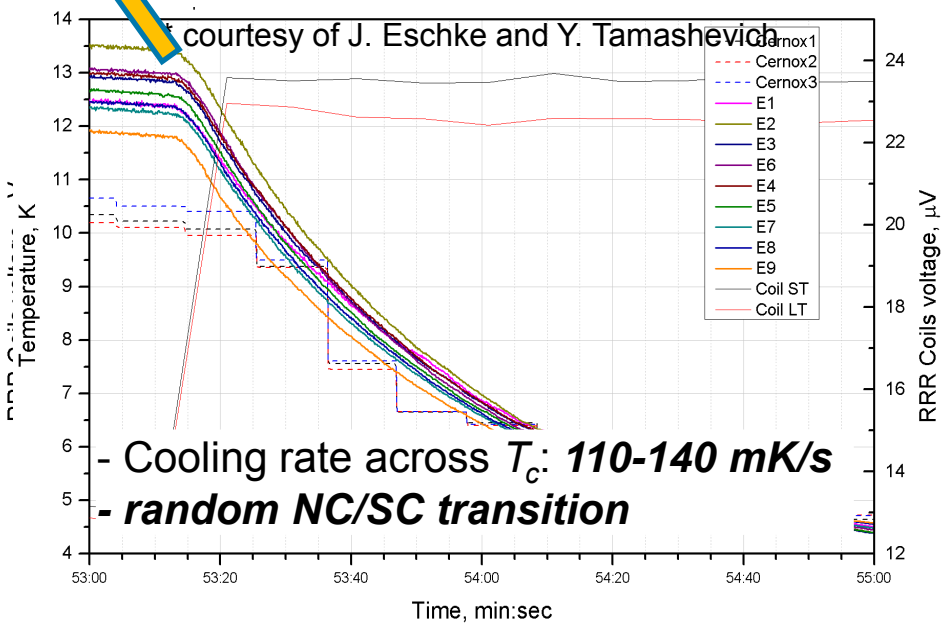




Nucleation of SC at „**slow**“ cooling rate
-> **bad** flux expulsion

* idea from FNAL, A. Romanenko et al., JAP 115, 184903 (2014)





- Smooth NC/SC transition is rather due to T **gradient** and **time** than **cooling rate**
- More results coming soon (TTC 2014?)

Centrifugal Barrel Polishing (CBP) of Nb cavities

How to repair cavities?

- Which kind of defects can be removed by CBP?
- How does CBP influence on cavities performance?

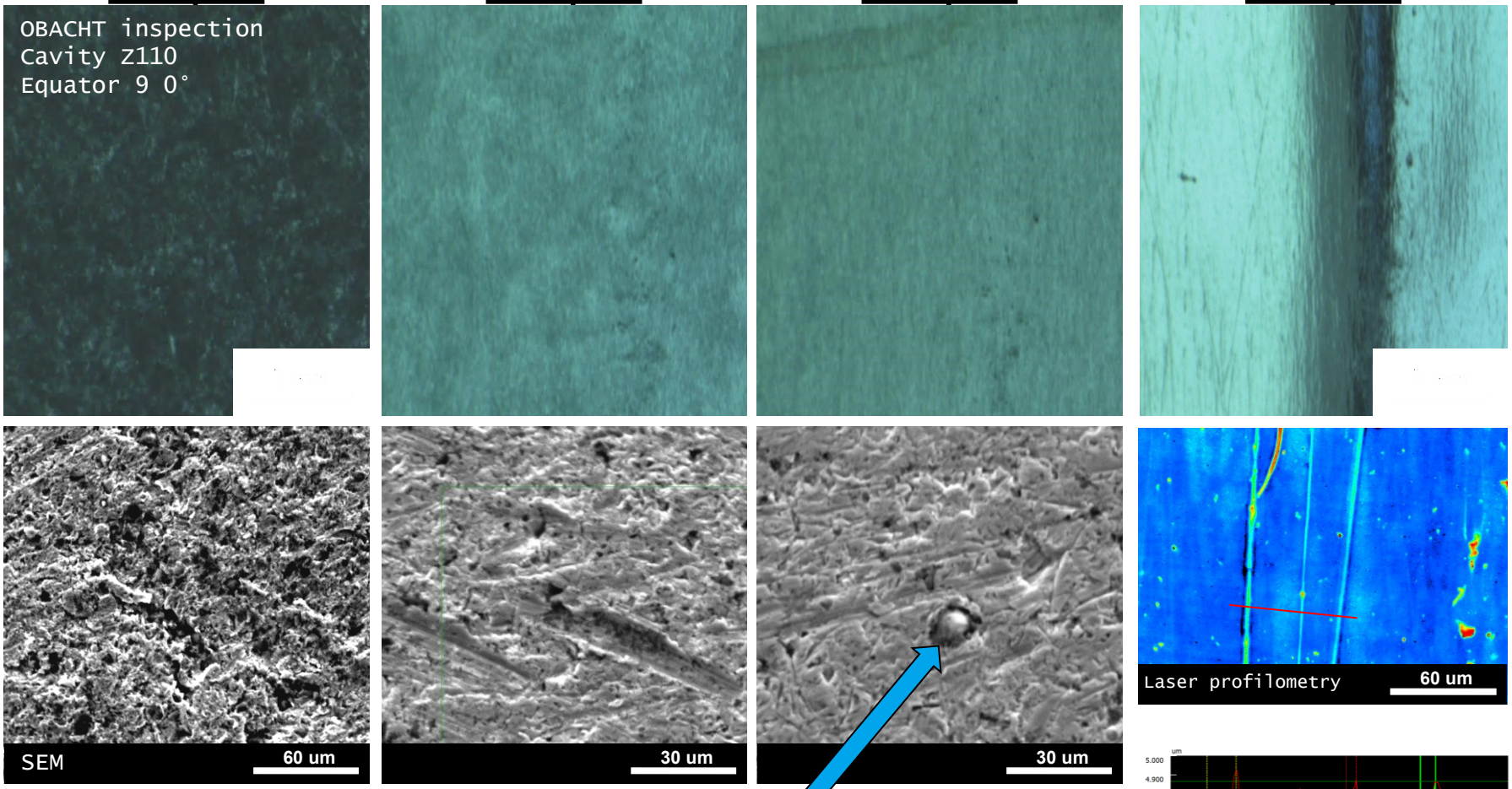
Can we replace bulk EP?

- Can CBP be used to remove Nb damaged layer (~150 μm) instead of bulk EP?
  -> cheap, safe, “green”
  -> no sulphur contamination?
  ->…….
- Can CBP be integrated in the existing production flow?

The CBP machine is being commissioned based on the polishing recipes derived from best FNAL, JLAB, and previous DESY experience

CBP of Nb cavities: OBACHT+SEM+EDX+ Replica/3D Laser profilometer analysis

Step 1 | Step 2 | Step 3 | Step 4

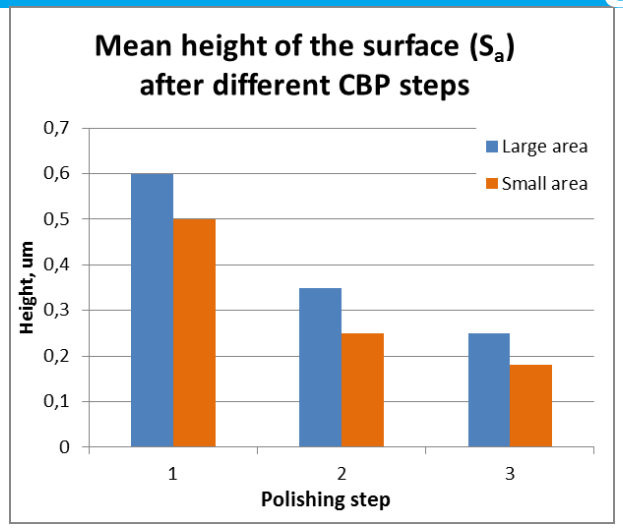


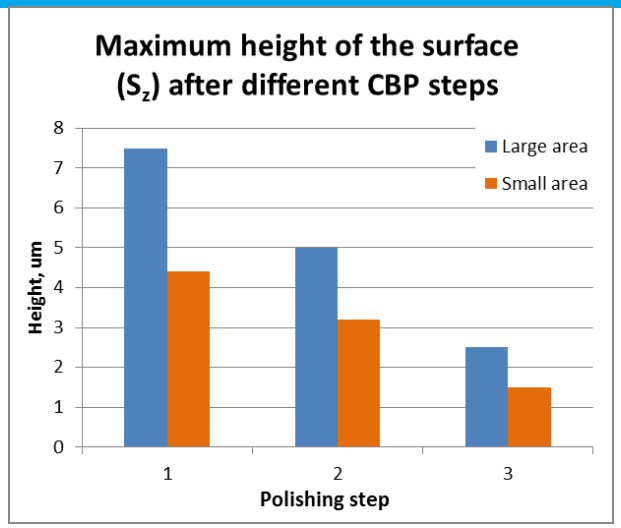
Embedded particle of polishing media (Al_2O_3)

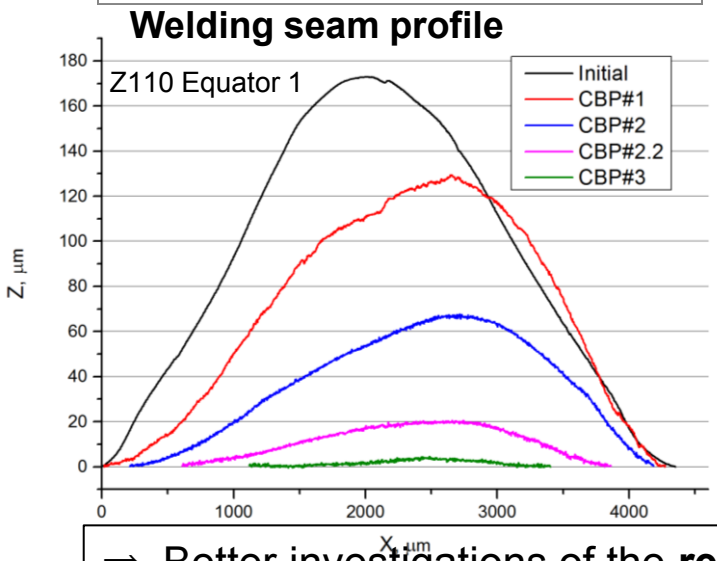
⇒ ***Embedded polishing media is an issue***

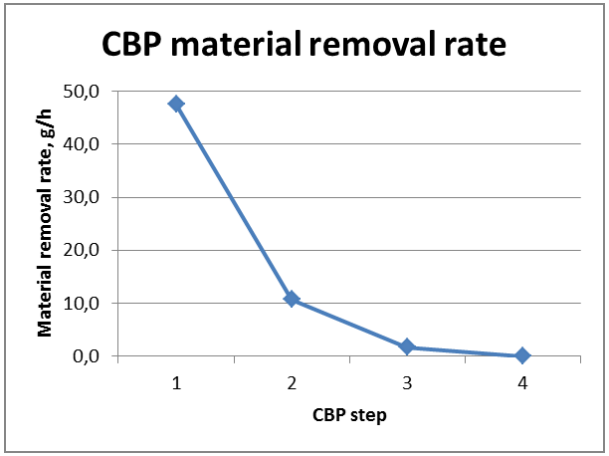
Welding seam profile

CBP of Nb cavities: roughness and removal analysis



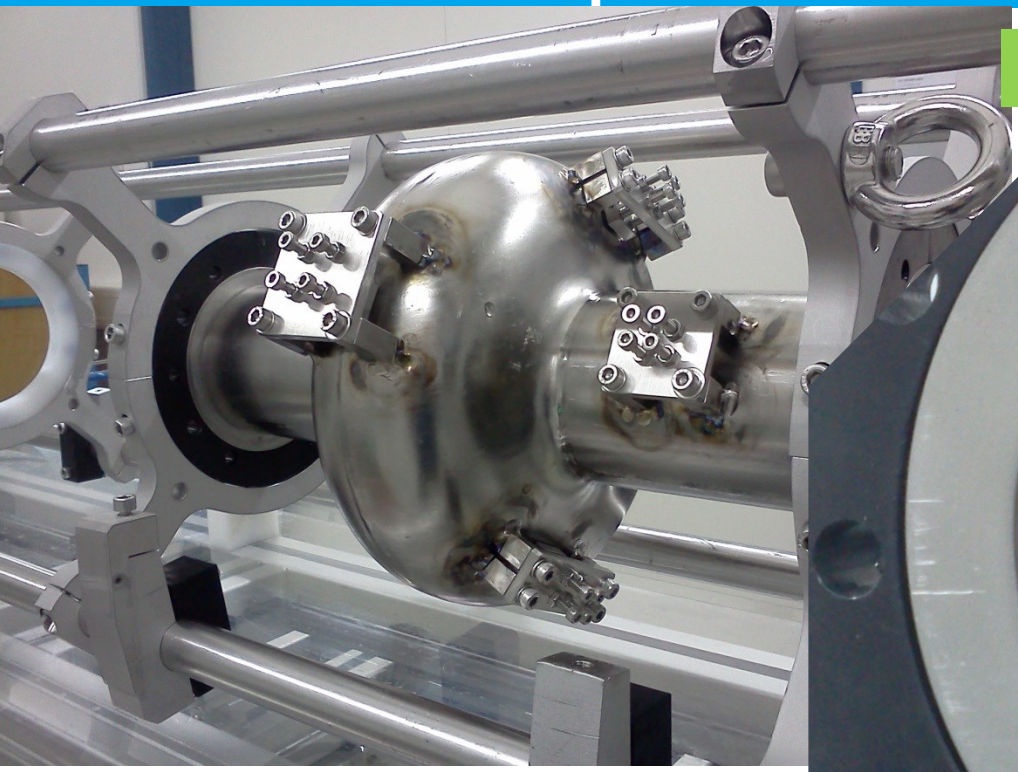




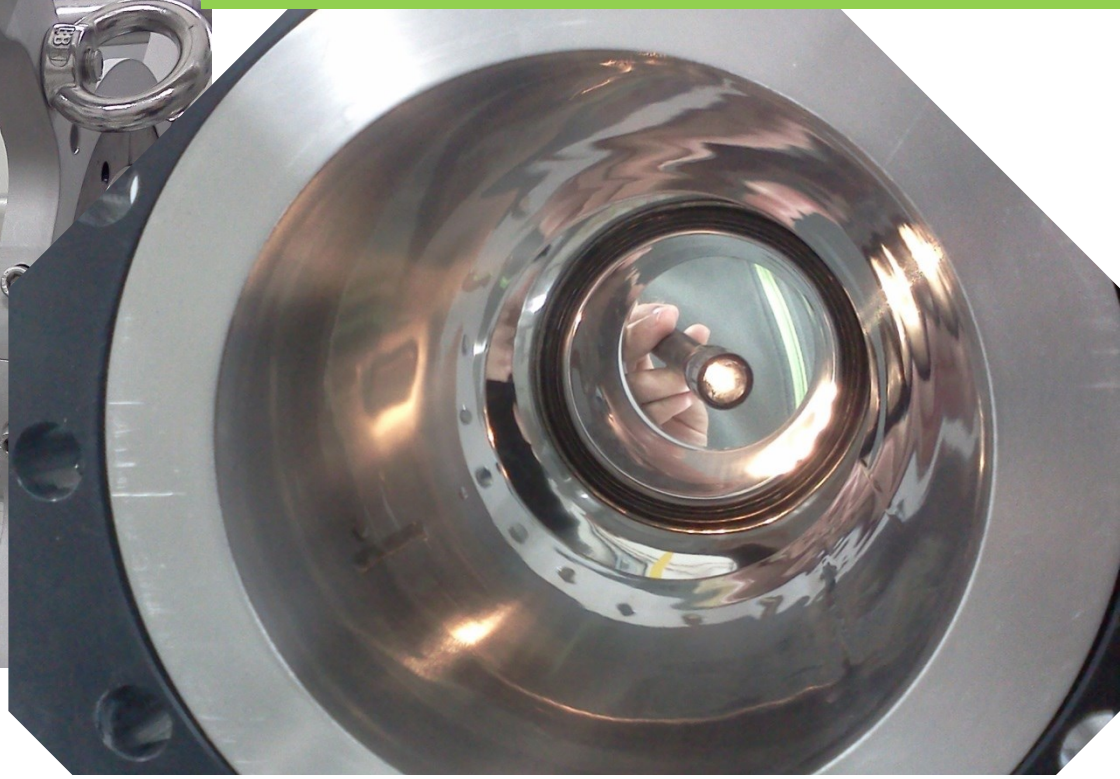


⇒ Better investigations of the **removal profile** required
⇒ Better **matching** of the polishing steps needed?
-> some scratches and polishing media still present
⇒ Polishing time to be reduced
⇒ Mechanical cavity deformation is an issue

CBP experiments with a coupon cavity



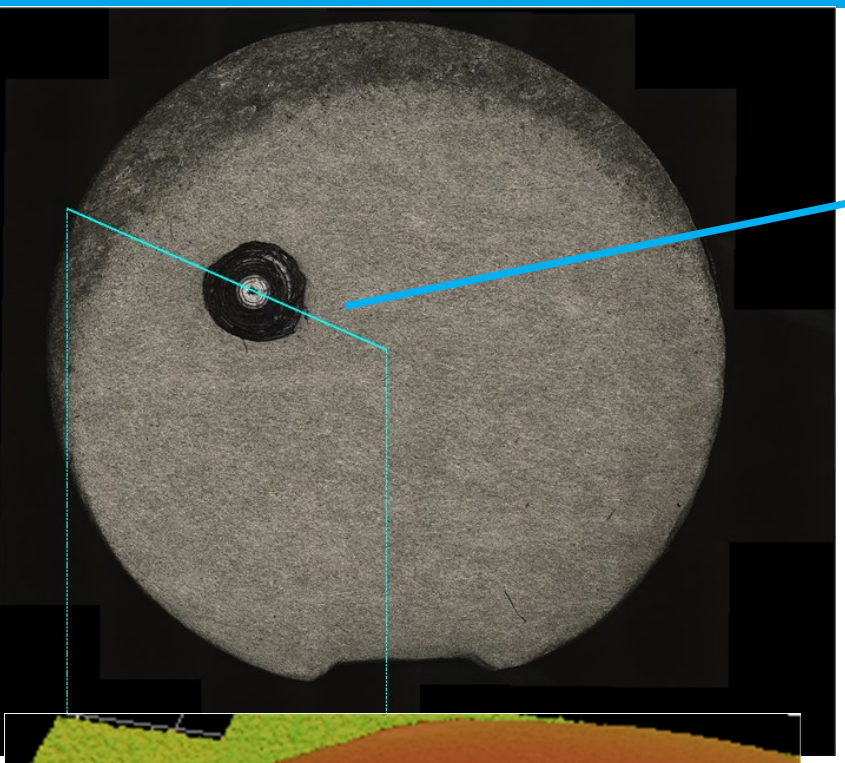
Mirror finish surface of the coupon cavity:

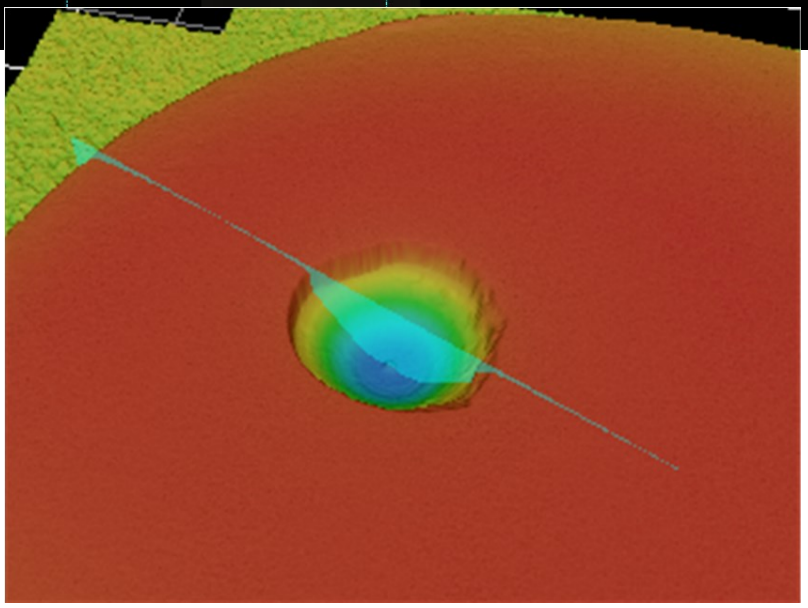


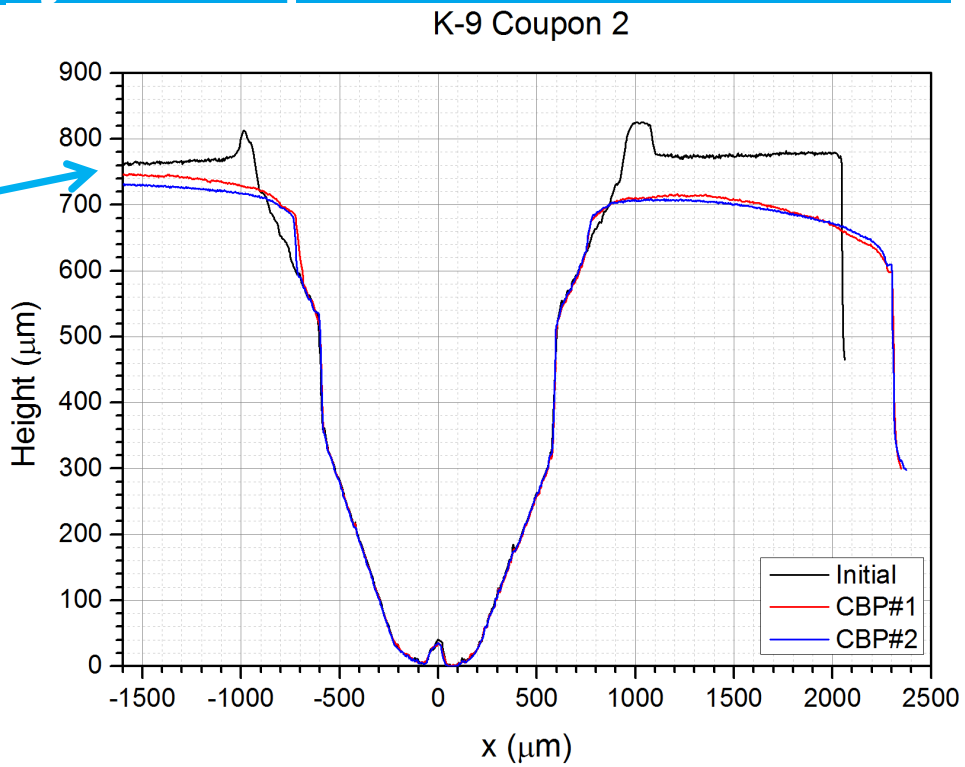
* pictures of Y. Tamashevich

- 1-cell coupon cavity
- 6 removable samples (coupons, 2 each for equator, cell side, and end tube)
- Facilitate polishing optimization:
  --> direct measurements of the surface roughness, removal rate, removal profile
  --> material analysis in the interesting regions

Profilometry of coupons



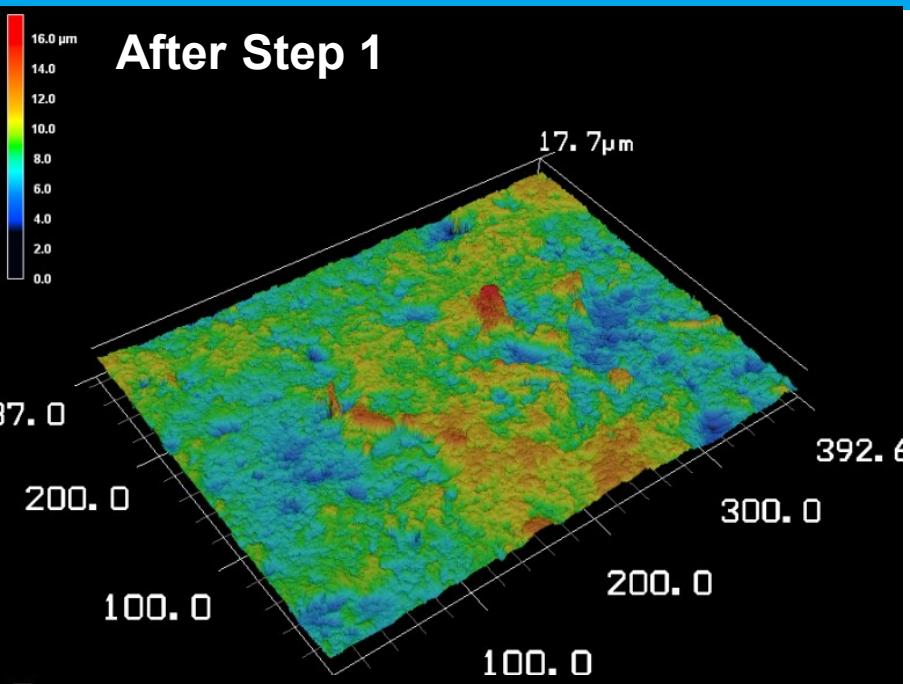


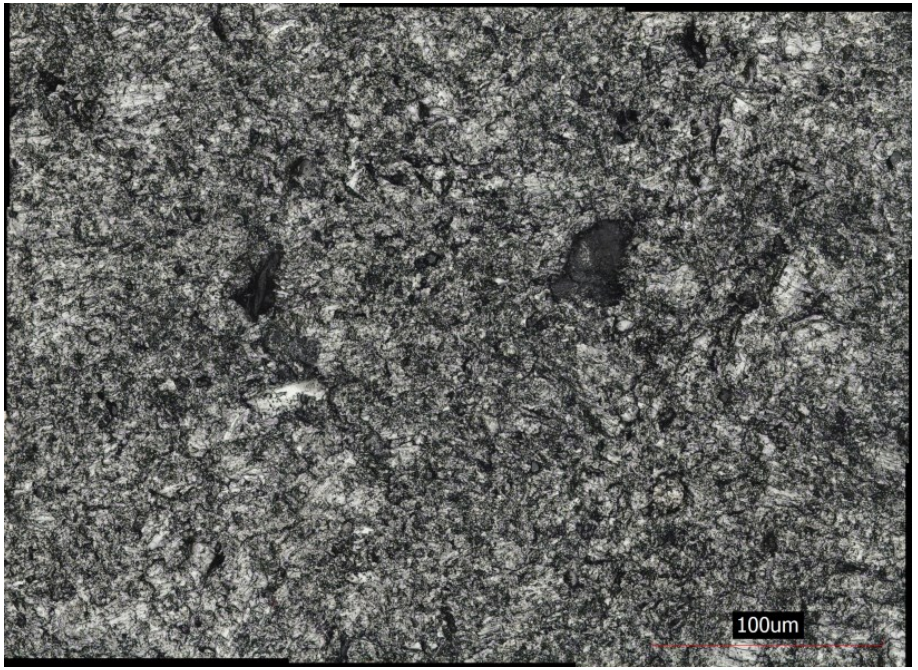


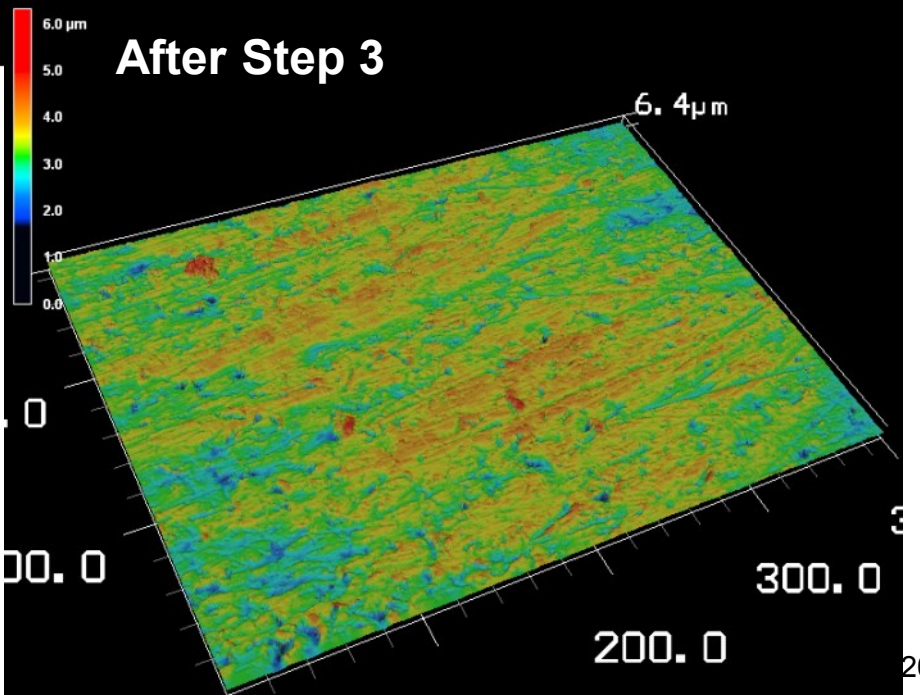
* courtesy of Y. Tamashevich

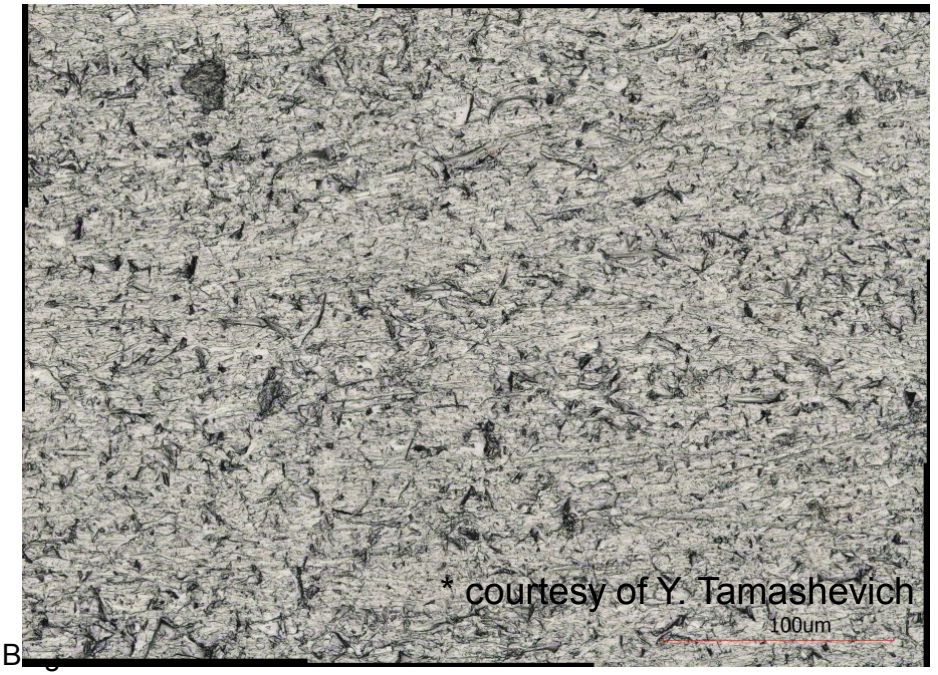
- Amount of removed material can be directly measured with submicron resolution
- Removal profile can be directly determined by comparing 6 coupons

Profilometry of coupons

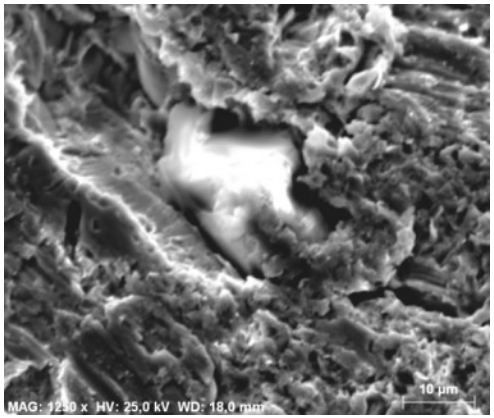


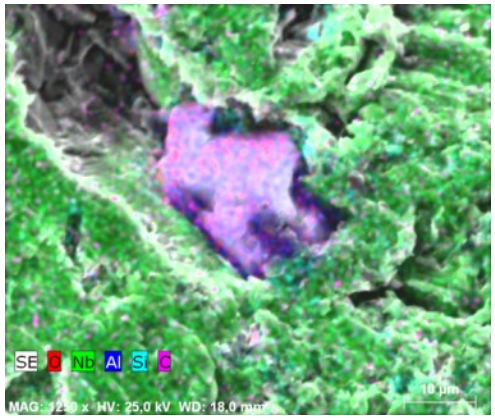




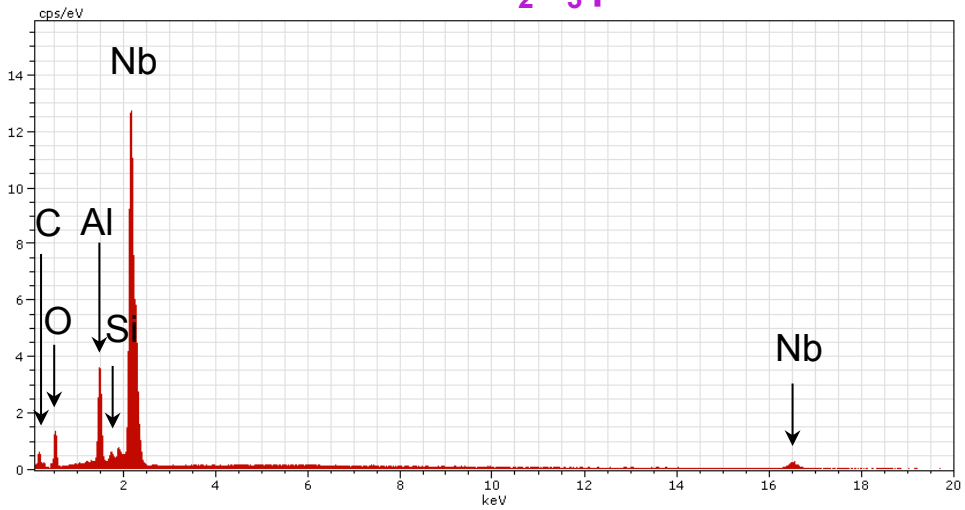


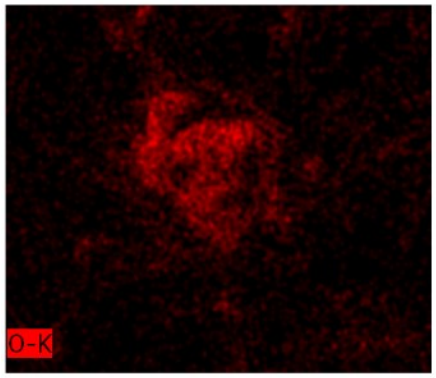
Surface/material analysis of coupons

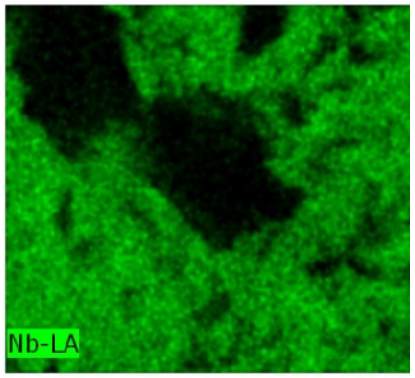


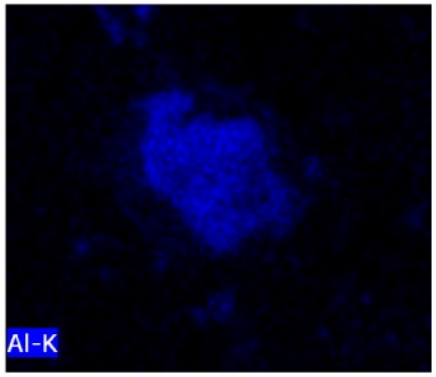


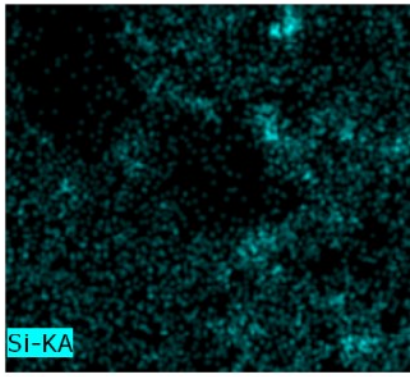
Al_2O_3 particle

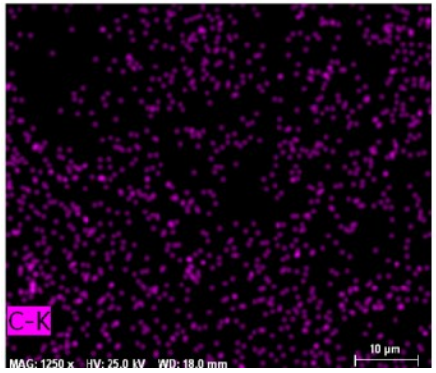






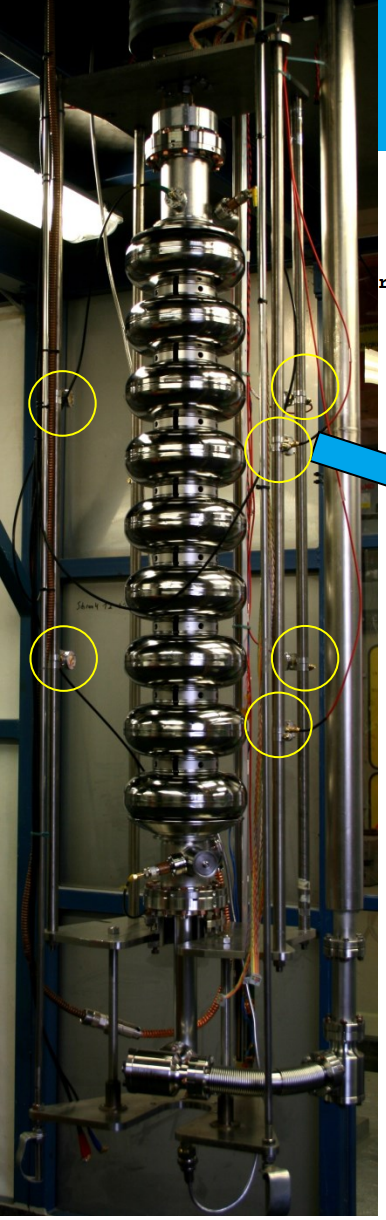




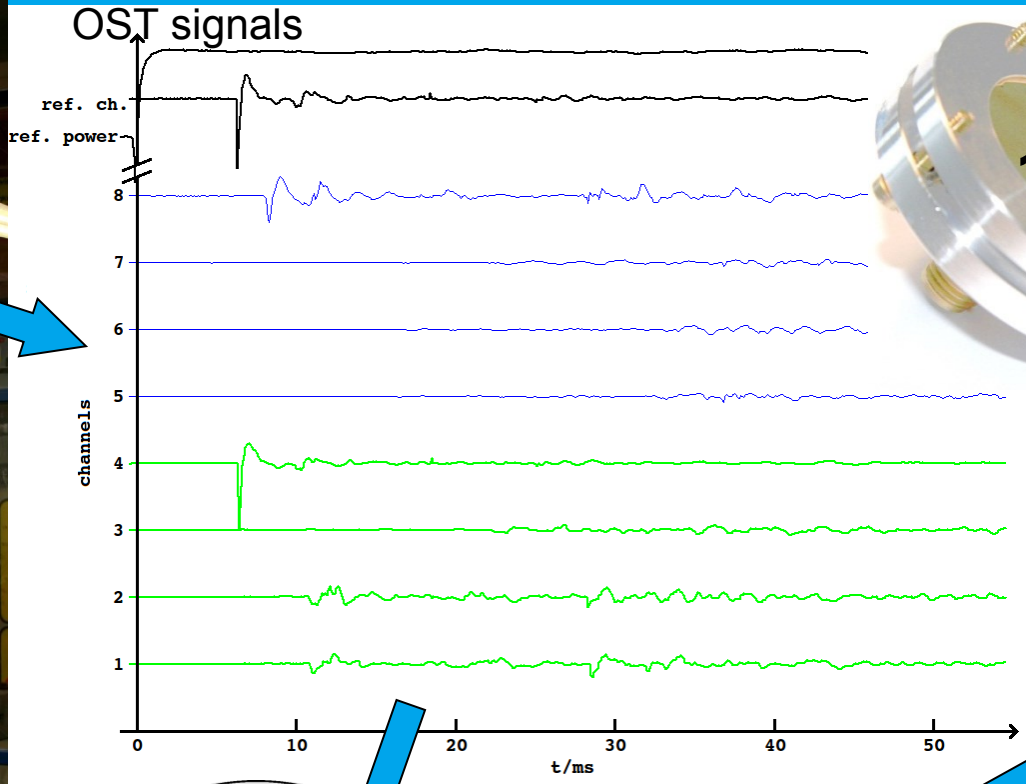


* courtesy of A. Prudnikava

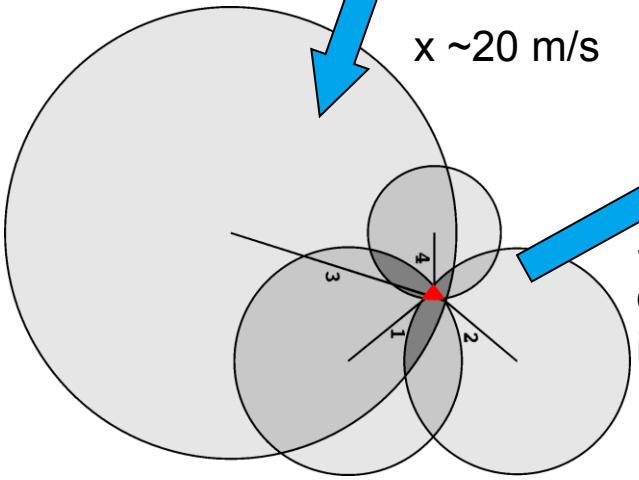
Quench localization by Second sound



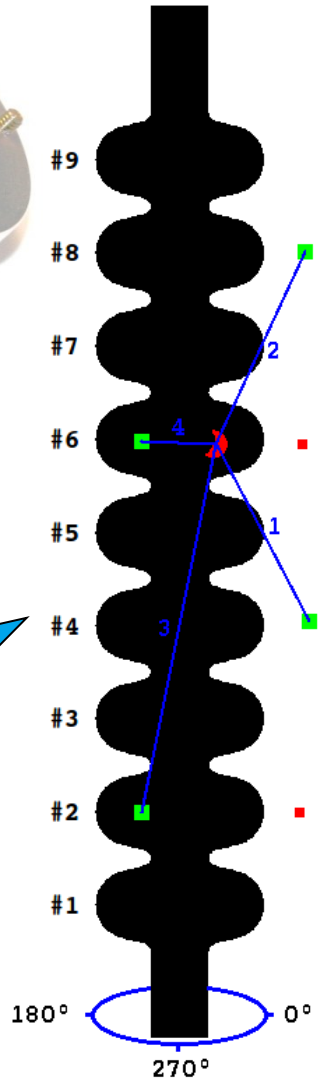
OST signals



x ~20 m/s



Schematic drawing of determination of the intersecting volume



Calculation result

* F. Schlander, PhD Thesis 2013

“Mapping” new approach the SS quench localization

Main ideas:

→ use information from all the OSTs

→ combination/overlap of pre-calculated “d**istance maps”**

Distance map:

-1	-1	-1	-1	-1	-1	-1
-1	-1	1	1	1	-1	-1
1	1	0	0	0	1	-1
0	0	1	1	1	-1	-1
1	0	-1	-1	-1	-1	-1

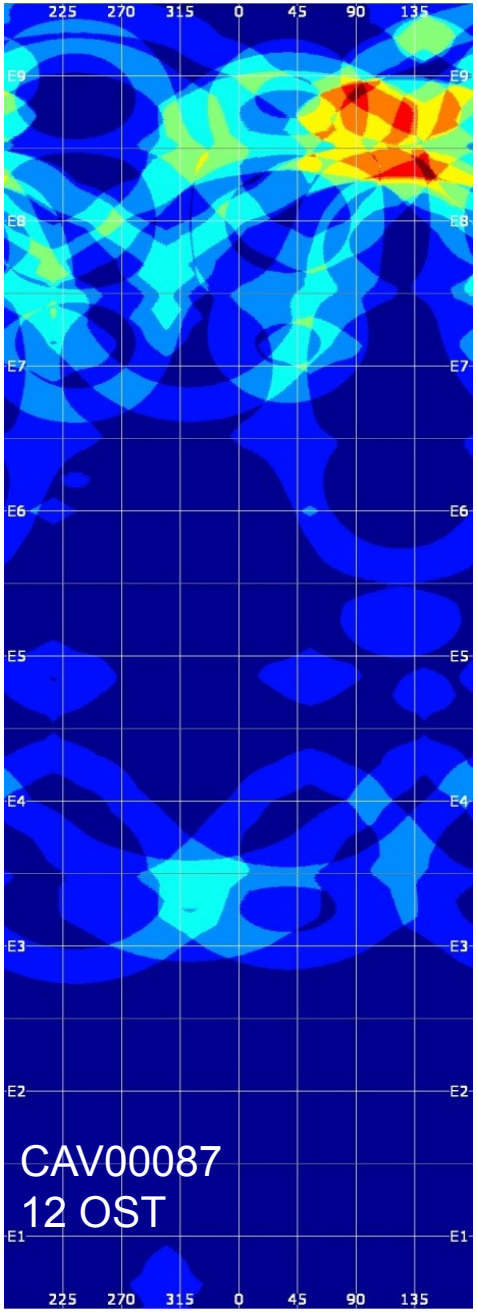
-1	-1	-1	-1	-1	1	0
-1	-1	-1	1	1	0	1
-1	-1	-1	1	0	1	-1
-1	-1	1	1	0	1	-1
-1	-1	-1	1	0	1	-1

Quench map:

-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	2	2	-1	-1
-1	-1	-1	1	0	2	-1
-1	-1	2	2	1	-1	-1
-1	-1	-1	-1	-1	-1	-1

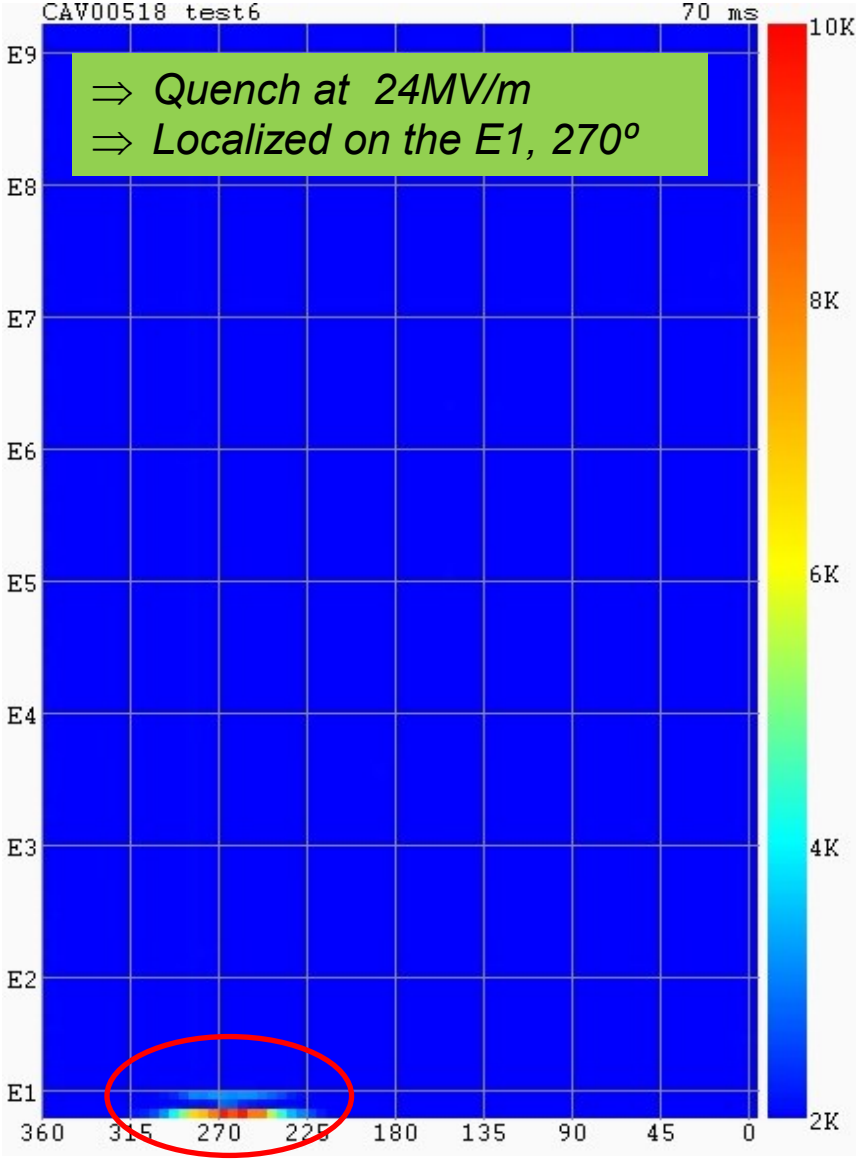
Easy, fast, and precise:

- No trilateration
- No manual pre-selection of channels
- Calculation of “distance maps” complex, but to be done only once.
- During and after the measurement the “distance maps” are searched, matched, and overlapped automatically
- Nice visualization of the results

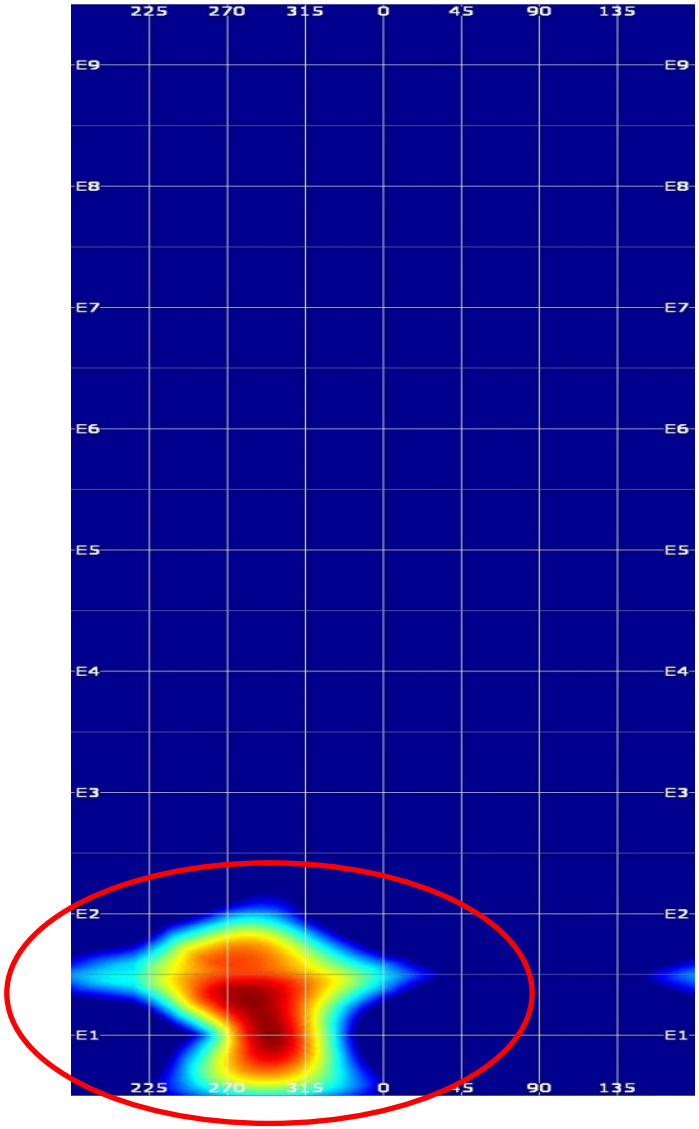


* Y. Tamashevich et al, to be published soon, more at TTC2014?

T-mapping vs. SS



⇒ *Quench at 24MV/m*
⇒ *Localized on the E1, 270º*



⇒ *Good agreement between T-mapping and SS-mapping results*
⇒ *OBACHT inspection of the quenching area coming soon*

* courtesy of Y. Tamashevich

Thank you for your attention !

Acknowledgements:

- **FLA/ILC group** and especially Yegor Tamashevich, Alena Prudnikava, and Ricarda Laasch

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