# SC Cavities; Material, Fabrication and QA

**W. Singer, DESY**

- Material for SC cavities
- Conventional Fabrication (deep drawing, EB welding)
- QA (quality assurance)
- Fabrication R&D (seamless, large grain LG and single crystal SC)

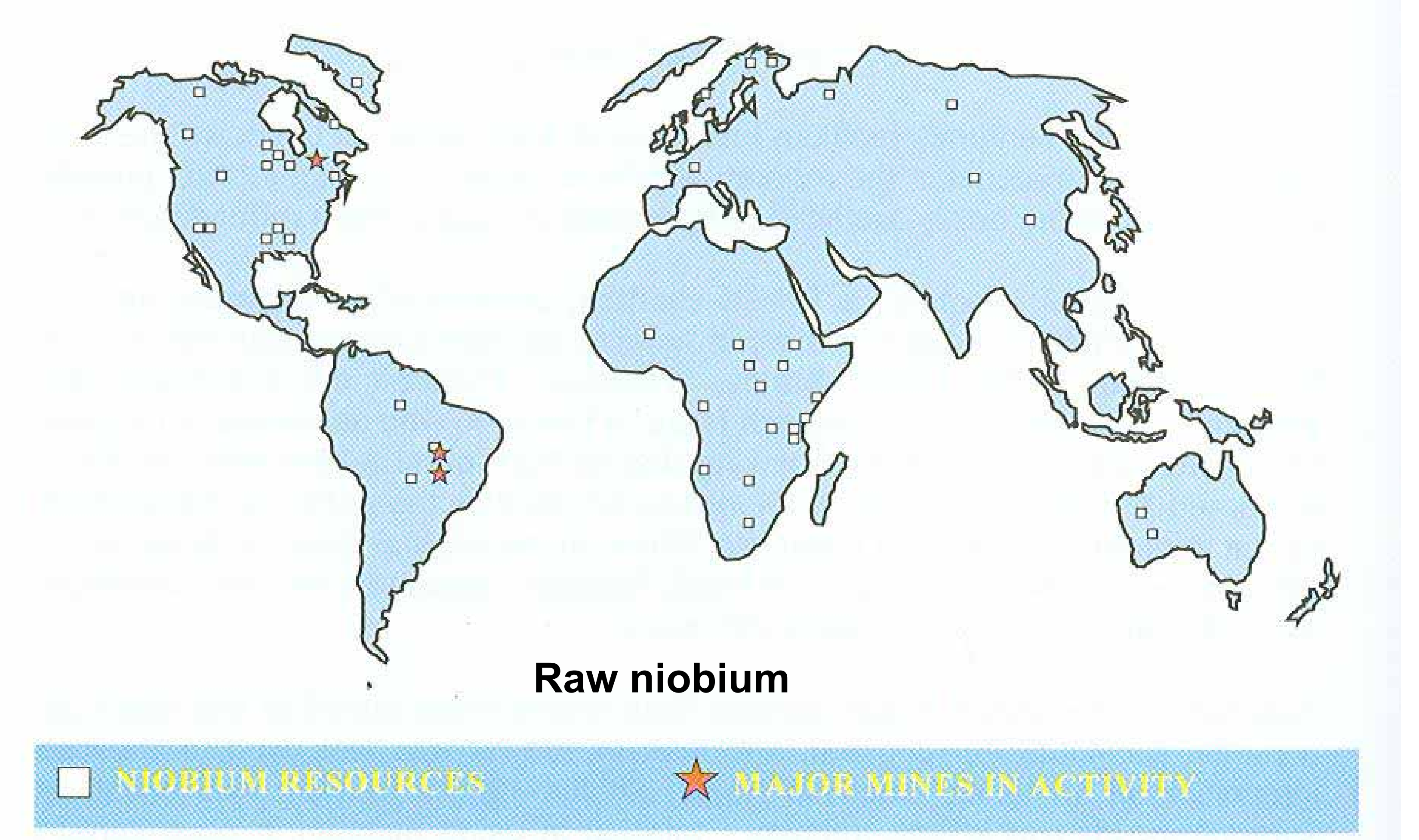
# Material

**Nb is a very valuable material**

**(Nb jewelry)**

## Nb is mostly used for SC cavities.

- high transition temperature Tc= 9,3 K
- high critical magnetic field Hc=200 mT
- chemically inert (surface covered by oxide layer)
- can be machined and deep drawn
- is available as bulk and sheet material in any size




Niobium is mostly obtained from mineral known as pyrochlore ($NaCaNb_2O_6F$). The pyrochlore mineral is processed by primarily physical processing technology to give a concentrate ranging from 55 to about 60% niobium oxide (Brazil, CBMM).

Columbite ((Fe, Mn)(Nb,Ta)$_2$O$_6$), a mineral with a ratio of $Nb_2O_5$:$Ta_2O_5$ ranging from 10:1 to 13:1, occurs in Brazil, Nigeria, and Australia, also other countries in central Africa. Niobium is recovered when the ores are processed for tantalum.

The world's largest niobium deposit is located in Araxá, Brazil owned by Companhia Brasileira de Metalurgia e Mineração (CBMM). The reserves are enough to supply current world demand for about 500 years, about 460 million tons. The mining of weathered ore, running between 2.5 and 3.0% $Nb_2O_5$, is carried out by open pit mining without the need for drilling and explosives. Approximately 85 to 90% of the niobium industry obtains its niobium ores.

CBMM Plant

# Niobium Production at CBMM

- Niobium Ore in Araxa mine (open air pit) is pyrochlor with 2.5% $Nb_2O_5$
- The ore is crushed and magnetite is magnetically separated from the pyrochlor.
- By chemical processes the ore is concentrated in Nb contents (50 –60 % of $Nb_2O_5$)
- A mixture of $Nb_2O_5$ and aluminum powder is being reacted to reduce the oxide to Nb
- This Nb is the feedstock for the EBM processes

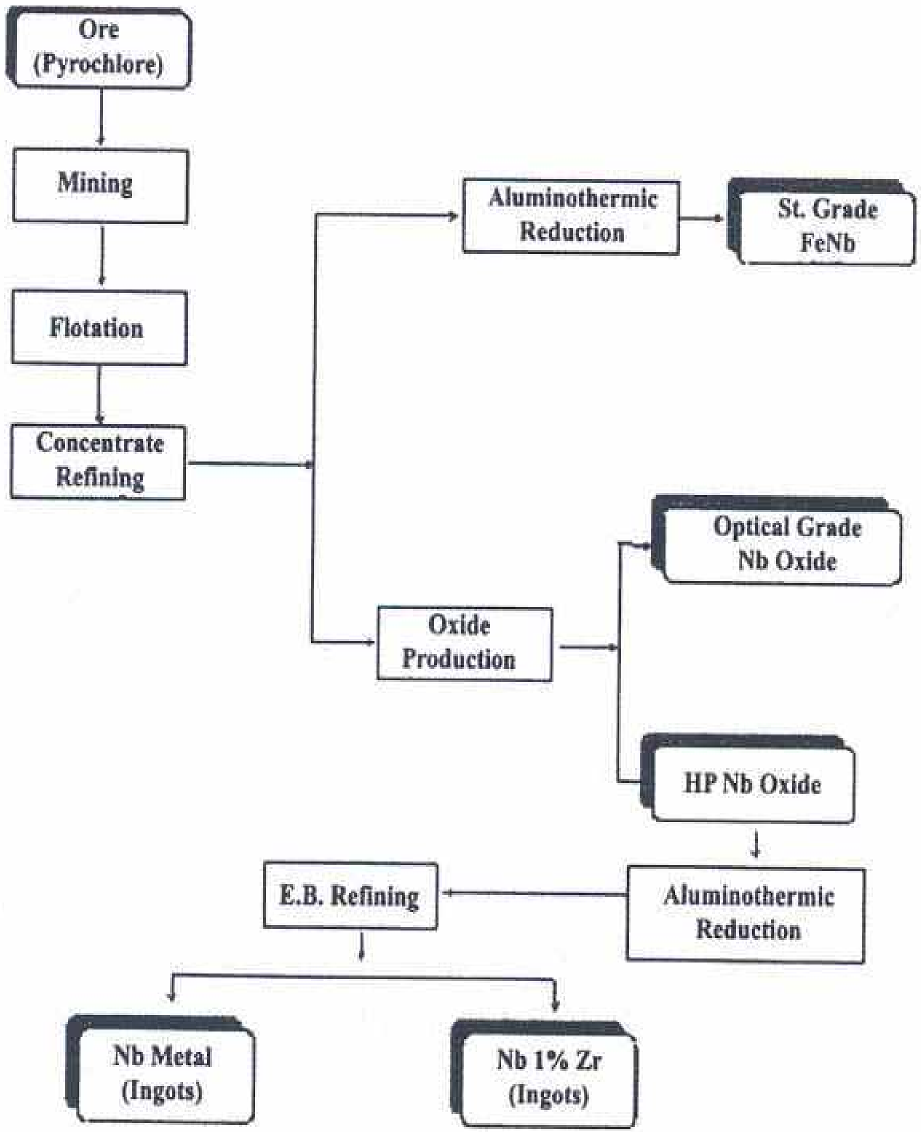
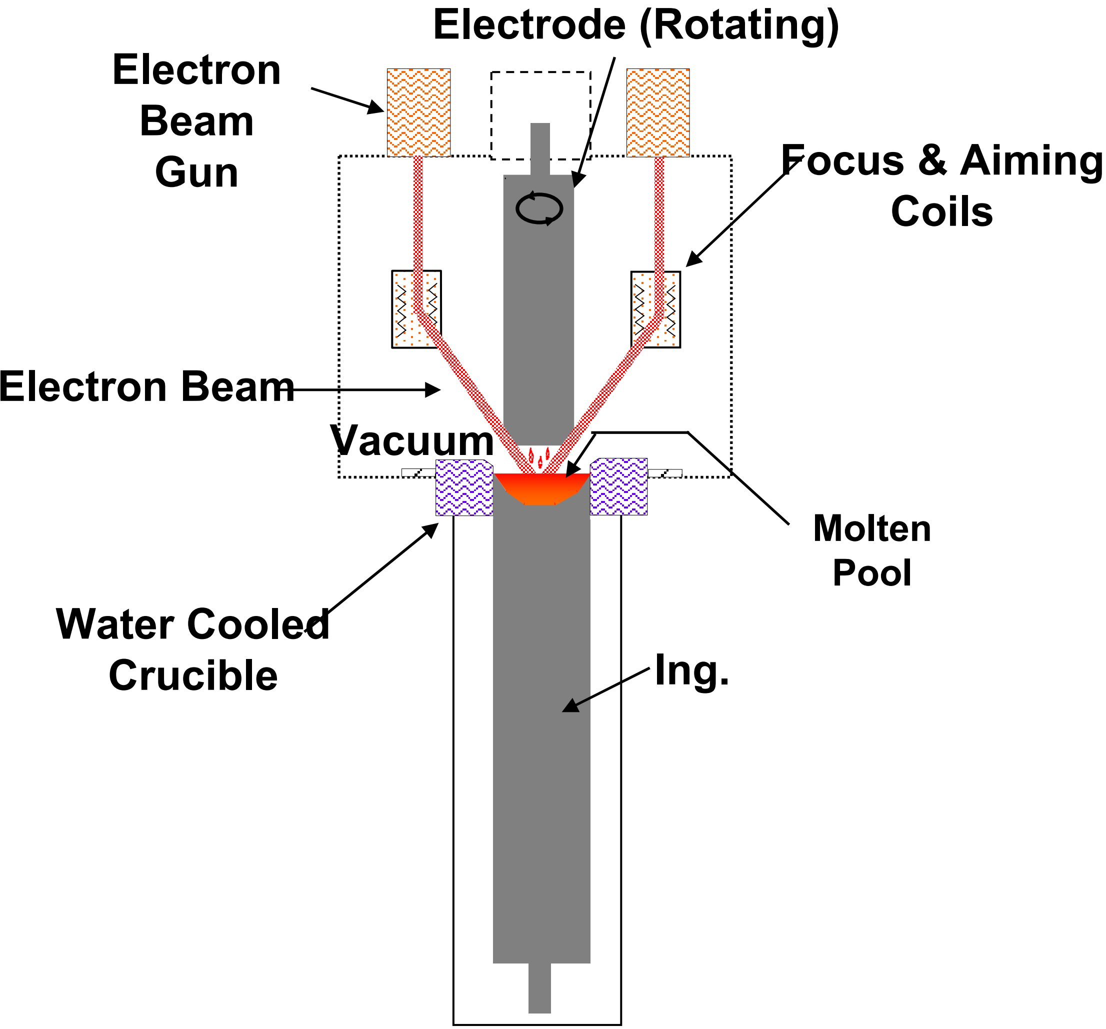



Fig. 3: Production flow chart at CBMM.

# Electron Beam Melting

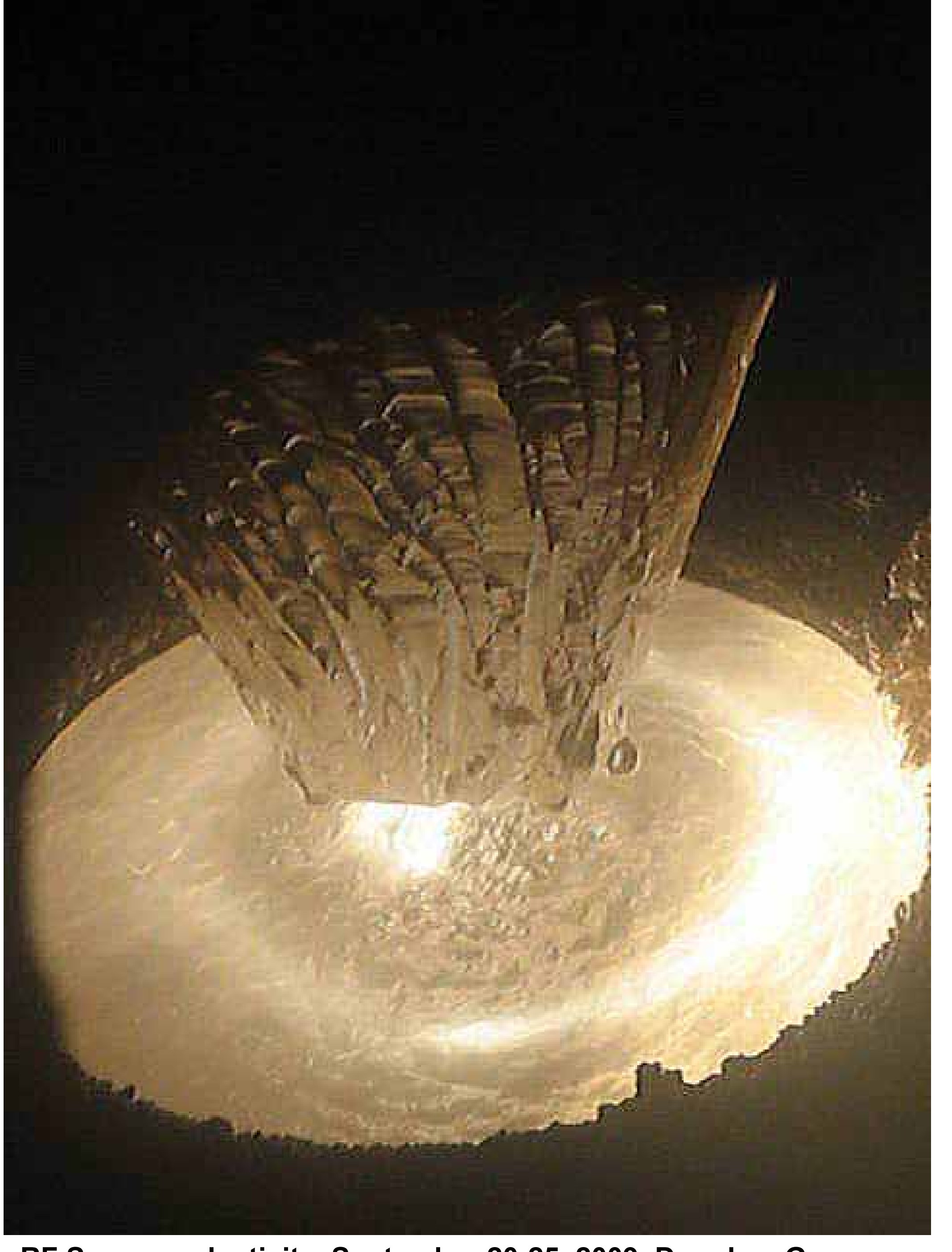



Electron beam melting of Nb

During of the ingot melts, molten metal globules fall into a pool on the ingot which is contained in a water cooled copper cylinder (sleeve). Impurities are evaporated and pumped away. Power impact is maintained to keep the pool molten out to within a few mm of the crucible wall. During melting the ingot formed is continuously withdrawn through the sleeve. The rate of withdrawal has to be carefully coordinated with the rate of the material to insure complete melting of the feed material and proper outgassing.

# Electron Beam Melting

As a result of the increasing demand for refractory metals in the last few decades, the electron-beam furnace has been developed to a reliable, efficient apparatus for melting and purification.



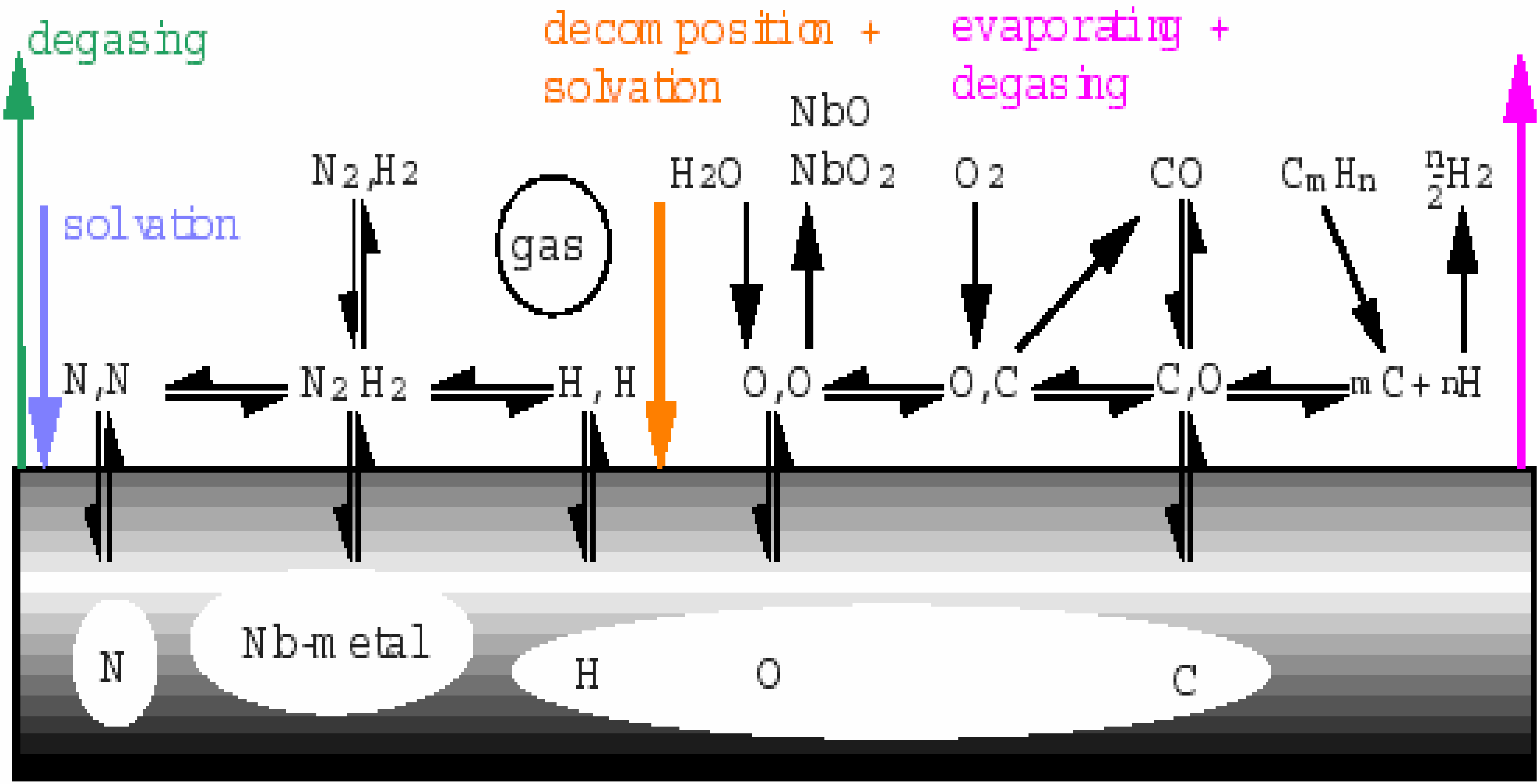
Fa. ALD (Germany) and VON ARDENNE (Germany) produces EB furnace for melting of refractory metals

One problem sometimes observed with e-beam melted ingots is the nonhomogeneous distribution of impurities.

The skin of the ingot has been found to contain more impurities than the inside.

Top to bottom inhomogeneity has also been observed. The first part of the melt which usually ends up at the bottom getters impurities in the early stages of the melt.

Machining away the skin cutting away a short section from the bottom are recommended for a purer final product




The melting temperature is a compromise between the maximization of purification and minimization of the material losses by evaporation.

RRR=300-500 are reachable currently

There are several companies, which can produce high purity refractory metals in larger quantities: Wah Chang  (USA), Cabot (USA), W.C.Heraeus (Germany), Tokyo Denkai (Japan), Ningxia (China), CBMM (Brasil), H.C. Starck (Germany, USA)

Control room (Wah Chang)

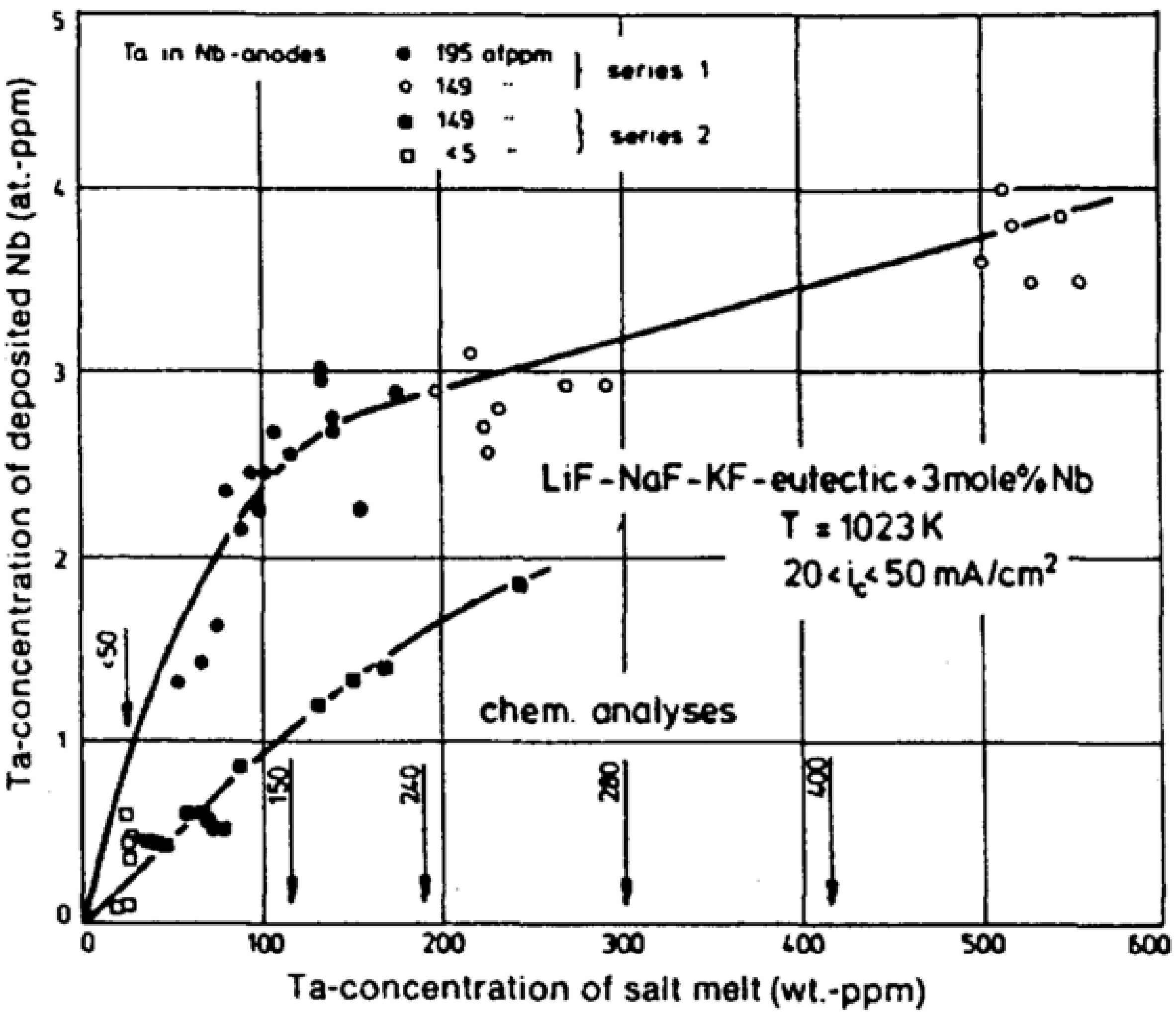
Electron beam melting furnace of CBMM (Brazil)

Finished ingot (Wah Chang). Diameter: 250-480 mm

Crucibles


Handling of EB melted ingots at CBMM (Brazil)

# Nb-Purification by Electrolysis in Molten Salts




Fundamental investigations of the electrodeposition of Nb- from LiF-NaF-KF melts containing $K_2NbF_7$, at T = 1000 K have shown that this electrolyte was not only suited for the production of coatings, but also that the material refined in this way;

Nb become extremely pure especially concerning of Ta

Efficiency of Nb-Purification by Electrolysis in Molten Salts.

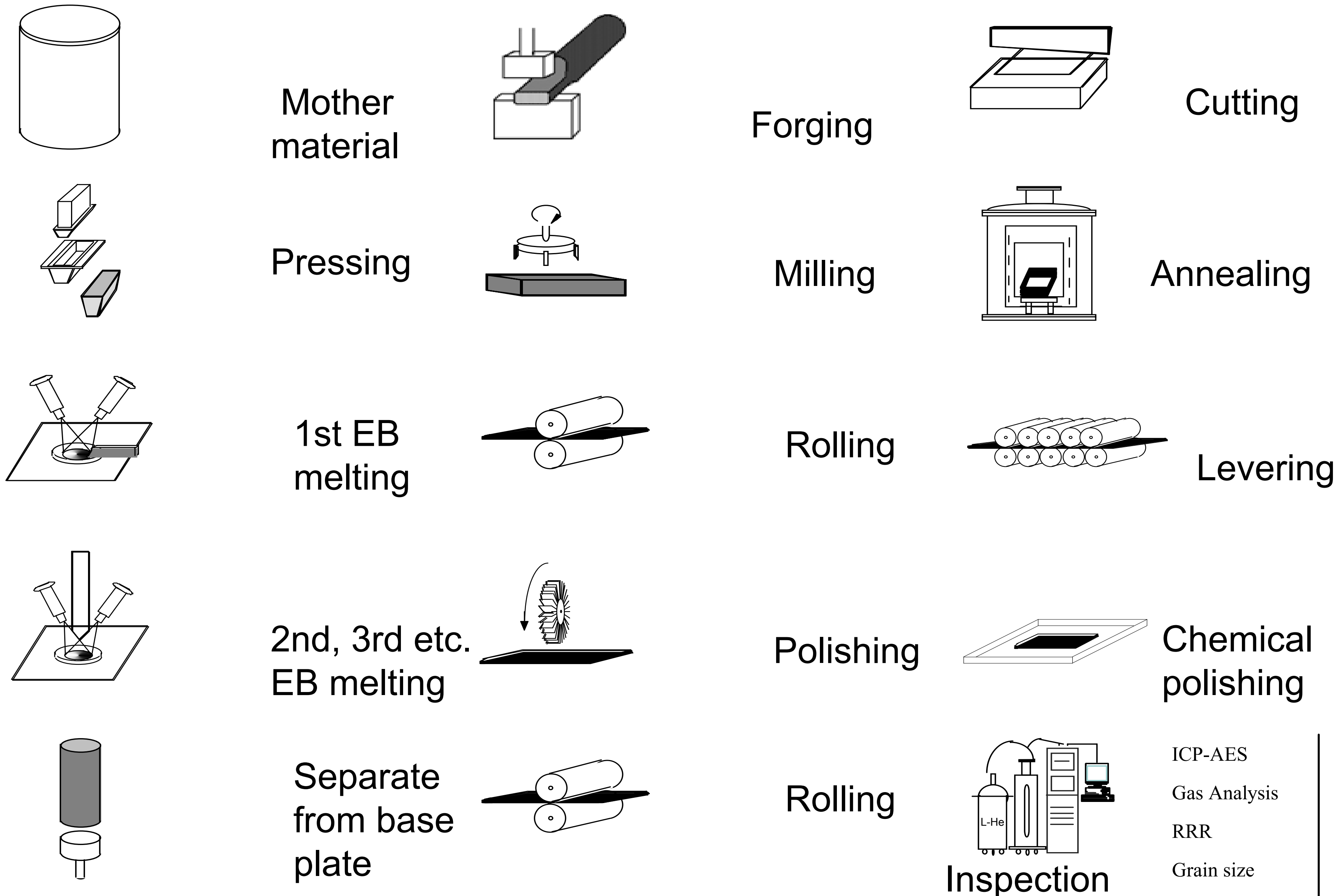
# Sheet : Technical Specification for High Purity Niobium

| Concentration of impurities in wt.ppm | | | | Mechanical properties | |
|---|---|---|---|---|---|
| Ta* | ≤ 500 | H* | ≤ 2 | Yield strength**, $\sigma_{0,2}$ | $50<\sigma_{0,2}<100$ N/mm$^2$ (Mpa) |
| W* | ≤ 70 | N* | ≤ 10 | Tensile strength** | > 100 N/mm$^2$ (Mpa) |
| Ti* | ≤ 50 | O* | ≤ 10 | Elongation at break** | 30 % |
| Fe* | ≤ 30 | C* | ≤ 10 | Vickers hardness** HV 10 | ≤ 60 |
| Mo* | ≤ 50 | RRR* | ≥ 300 | Absence of foreign material inclusions* | Proven by scanning |
| Ni* | ≤ 30 | Recrystal. degree. Grain size* ,** ? | ≈ 50 µm | Texture *, ** ? | |

* - relevant for performance

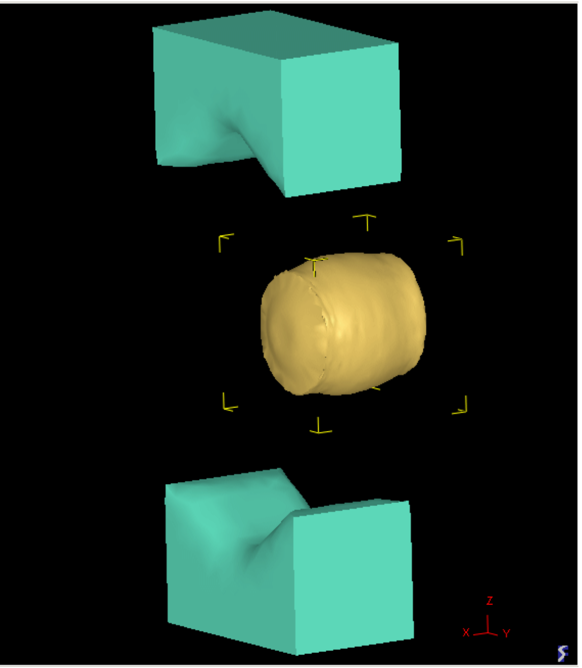
** - relevant for successful fabrication

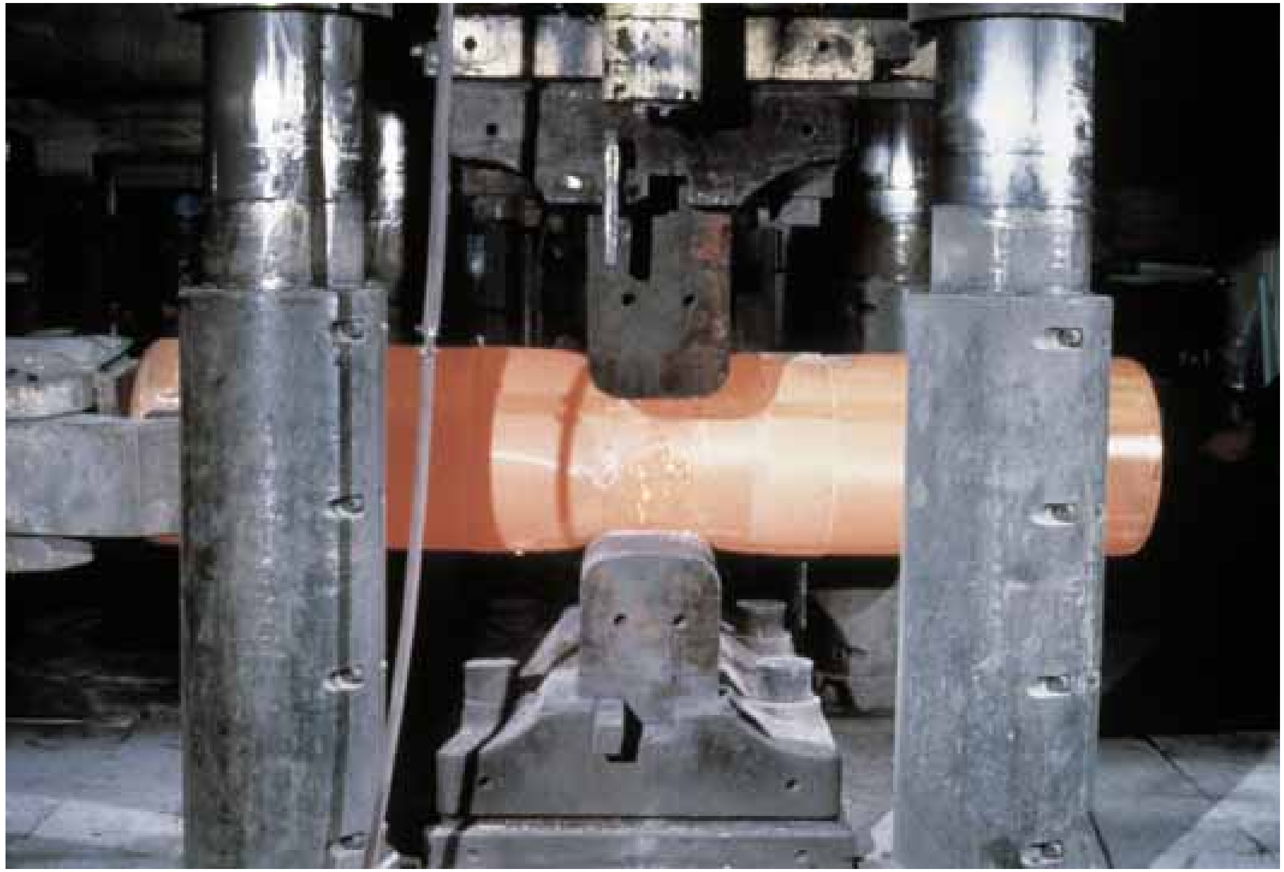
# Fabrication of Nb sheets at Tokyo Denkai




In the final sheet the purity of niobium should be not inferior as in the ingot

# Forging





2000 ton open die forge
(Wah Chang )

# Rolling

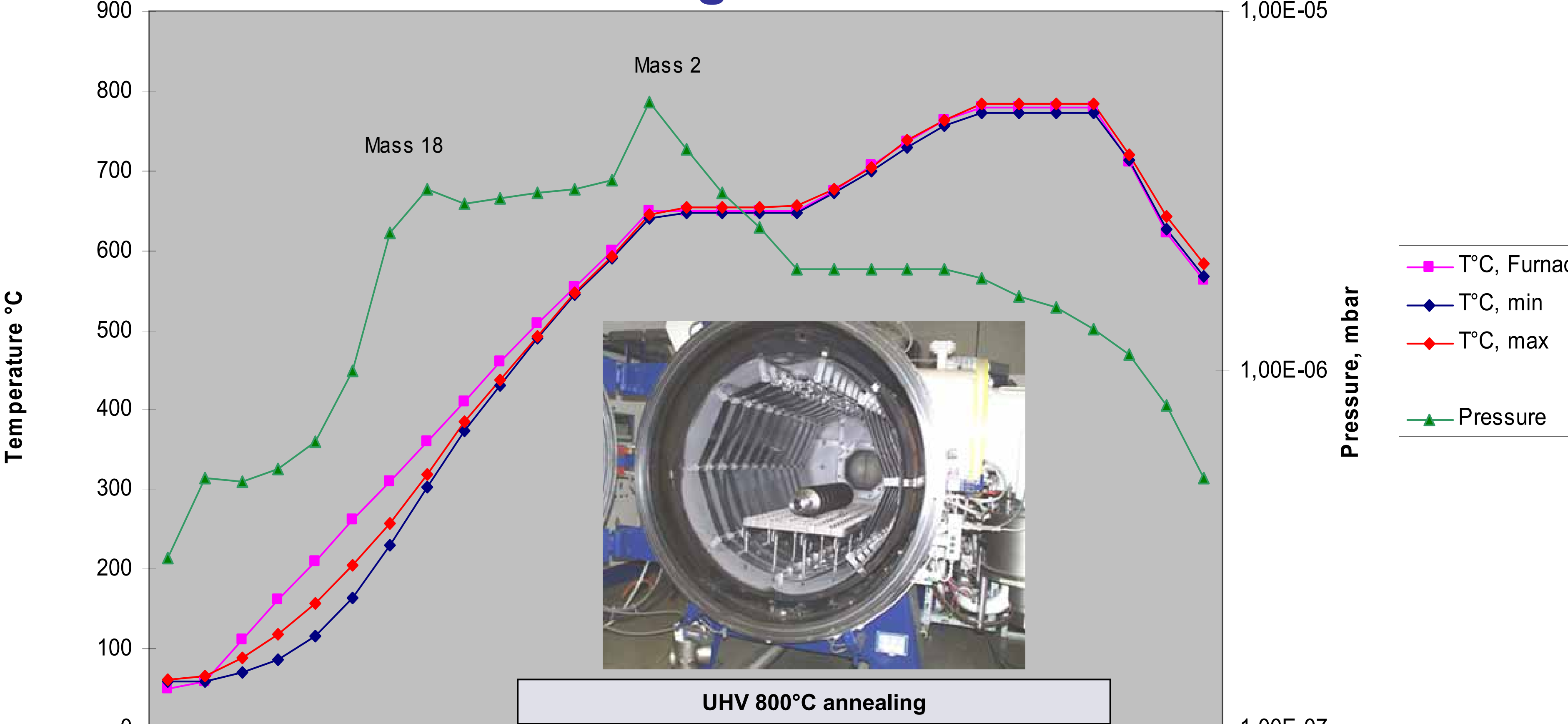
700 mm wide cold rolling mill (Wah Chang)

800 mm wide
hot rolling mill
(Wah Chang)

Hot rolling, used mainly to produce sheet metal is when industrial metal is passed or deformed between a set of work rolls and the temperature of the metal is generally above its recrystallization temperature.

Cold rolling takes place below recrystallization temperature.

# Annealing

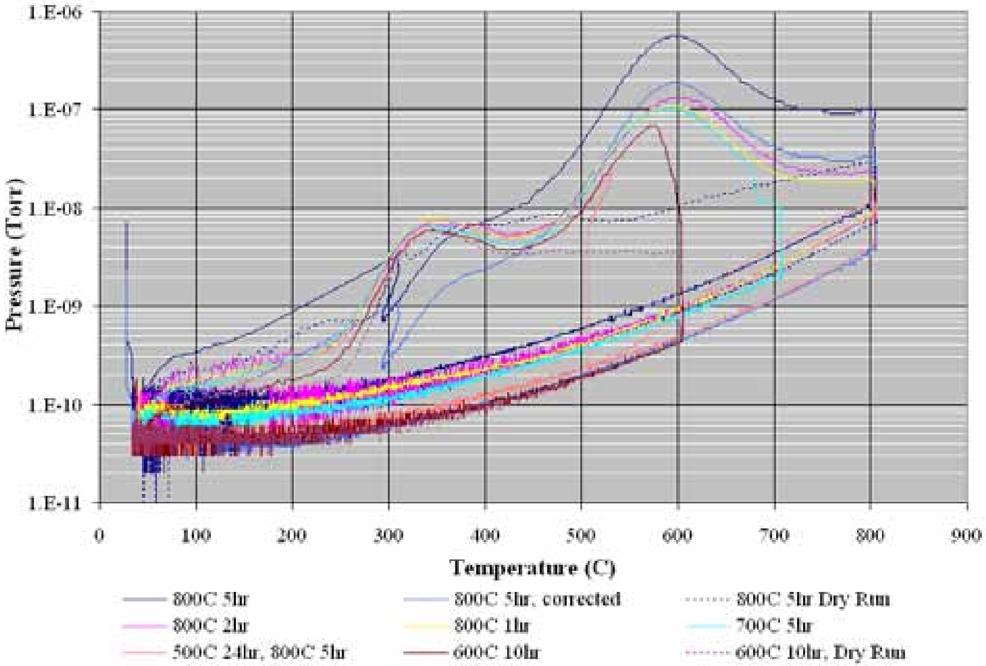



| | 08:30 | 08:45 | 09:00 | 09:15 | 09:30 | 09:45 | 10:00 | 10:15 | 10:30 | 10:45 | 11:00 | 11:15 | 11:30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T°C, Furnace | 50 | 59 | 112 | 161 | 210 | 261 | 310 | 361 | 411 | 460 | 507 | 554 | 600 |
| T°C, min | 60 | 60 | 70 | 87 | 117 | 165 | 229 | 304 | 374 | 430 | 489 | 544 | 591 |
| T°C, max | 61 | 65 | 89 | 119 | 157 | 205 | 257 | 319 | 384 | 438 | 492 | 547 | 593 |
| | | | | | | | | | | | | | |
| Pressure | 3,0E-7 | 5,0E-7 | 4,9E-7 | 5,3E-7 | 6,3E-7 | 1,0E-6 | 2,4E-6 | 3,2E-6 | 2,9E-6 | 3,0E-6 | 3,1E-6 | 3,2E-6 | 3,4E-6 |

| | 11:45 | 12:00 | 12:15 | 12:30 | 12:45 | 13:00 | 13:15 | 13:30 | 13:45 | 14:00 | 14:15 | 14:30 | 14:45 | 15:00 | 15:15 | 15:30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T°C, Furnace | 650 | 650 | 650 | 650 | 650 | 675 | 706 | 736 | 763 | 780 | 780 | 780 | 780 | 710 | 621 | 562 |
| T°C, min | 640 | 646 | 647 | 648 | 647 | 672 | 700 | 730 | 756 | 773 | 773 | 773 | 773 | 713 | 627 | 568 |
| T°C, max | 645 | 655 | 655 | 654 | 656 | 677 | 705 | 738 | 763 | 783 | 783 | 783 | 783 | 721 | 642 | 583 |
| | | | | | | | | | | | | | | | | |
| Pressure | 5,6E-6 | 4,1E-6 | 3,1E-6 | 2,5E-6 | 1,9E-6 | 1,9E-6 | 1,9E-6 | 1,9E-6 | 1,9E-6 | 1,8E-6 | 1,6E-6 | 1,5E-6 | 1,3E-6 | 1,1E-6 | 8,0E-7 | 5,0E-7 |

The temperature and the total pressure in the chamber during annealing of Nb300.

# Outgassing of hydrogen




Hydrogen partial pressure versus annealing temperature

During the high-temperature annealing of niobium in vacuum, hydrogen is picked up at the surface and the rate determining process is the transport in the gas atmosphere or the diffusion in the bulk, depending on the partial pressure and the diffusion rate.

It must also be taken into account that considerable quantities of H may be picked up during cooling down.

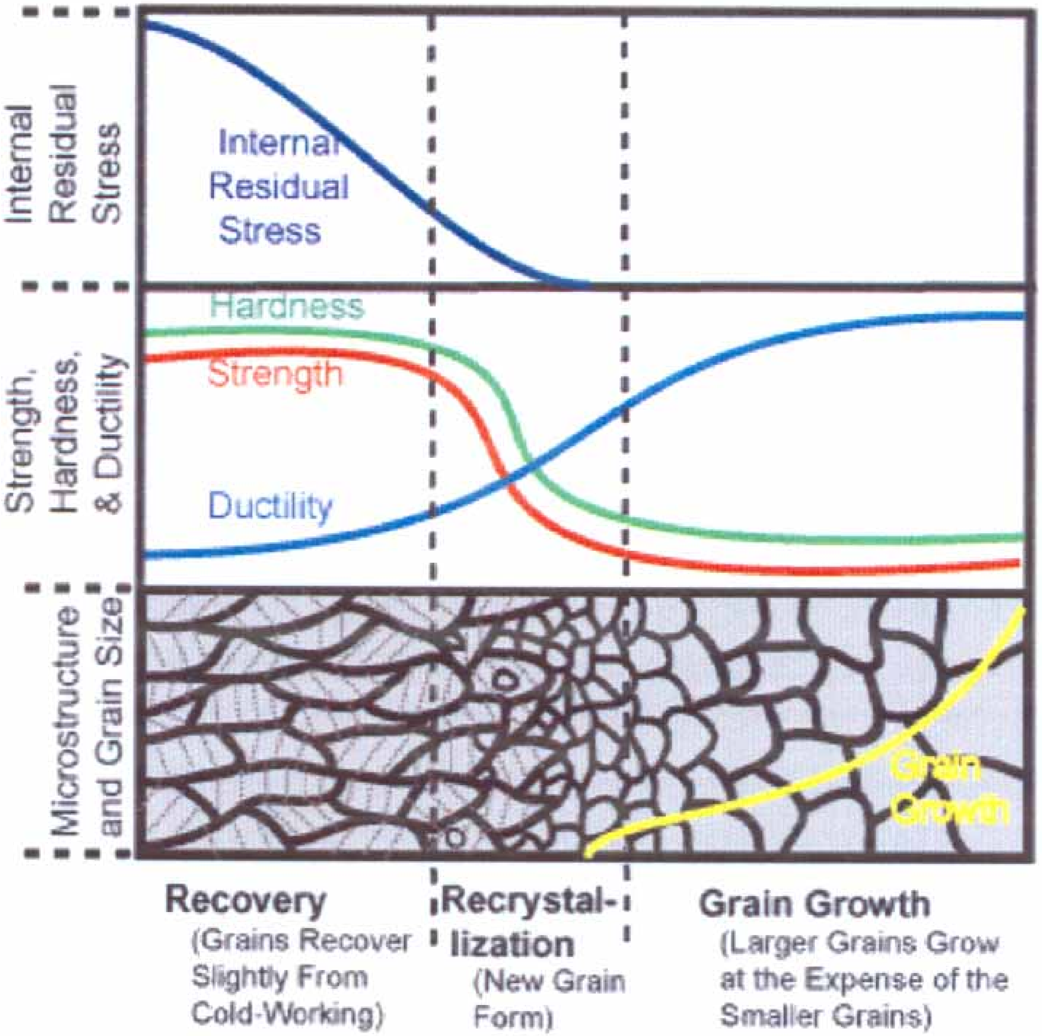
The rate of H absorption depends on the relative number of $O_2$ or $H_20$ and $H_2$ molecules touching the surface per time unit.

**How the outgassing of hydrogen take place**?

Nb hydrides decomposes mostly at T> 100-150°C. Outgassing of hydrogen is however not possible at these temperatures because the $Nb_2O_5$ protecting layer is stable up to 250-300°C. The most efficient annealing of high purity niobium is 750-800°C, 2 hours.

• Complete outgassing of hydrogen

• Recrystallization of Nb. That means lattice has less defects and become less vulnerable to a new hydrogen contamination




## Recrystallization

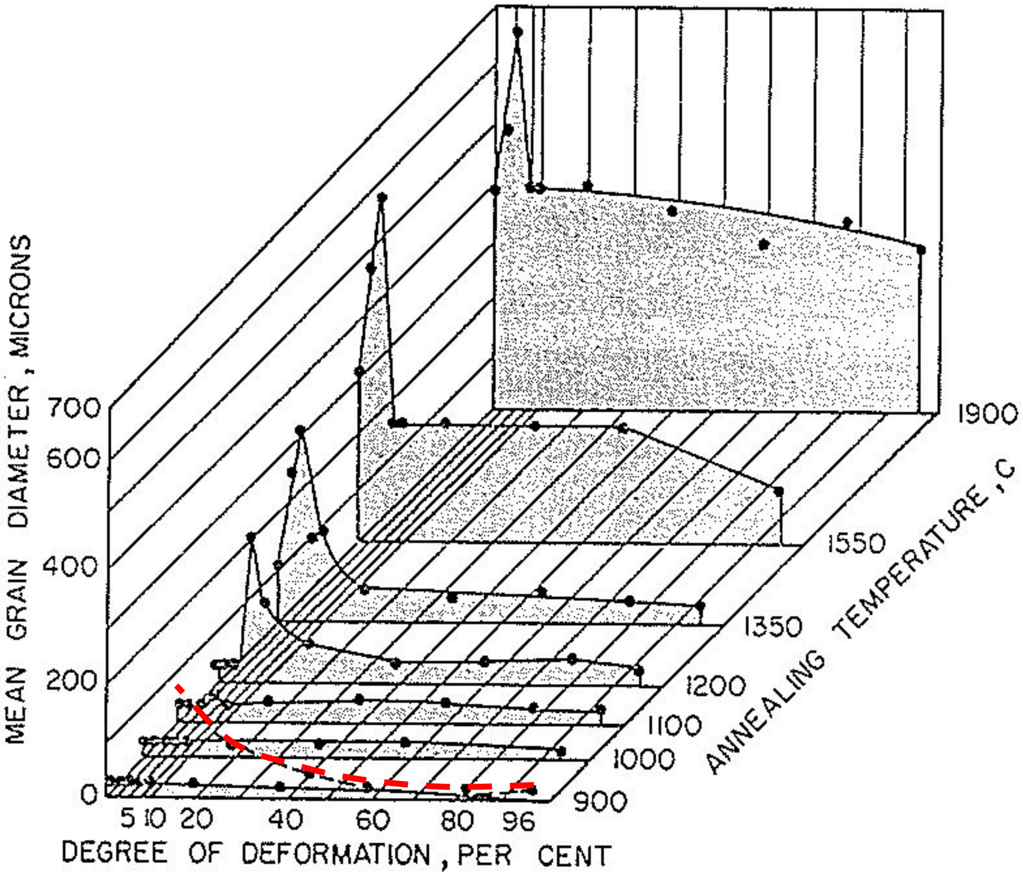
Choosing the proper annealing conditions is important to produce the correct grain size near 100% recrystallization and keep the highest possible purity (RRR).

Recovery: - removing during annealing the point defects, decrease and change of orientation of dislocations

Recrystallization: - nucleation of new grains and growing of new crystals

Grain growth: - grain size increases

Commercial "Pure Nb"
RRR ~ 50-100




- deformation > 65% =>
  - uniform nucleation
  - small grains
- if purity ↑, $T_{recryst}$ ↓
  - RRR ≤ 100 => $T_{recryst}$ ≥ 900 C
  - RRR 300 => $T_{recryst}$ ~ 800 C*
  - RRR 400 => $T_{recryst}$ ~ 750 C ?


**Not completely recrystallized Nb**


**Completely recrystallized Nb**

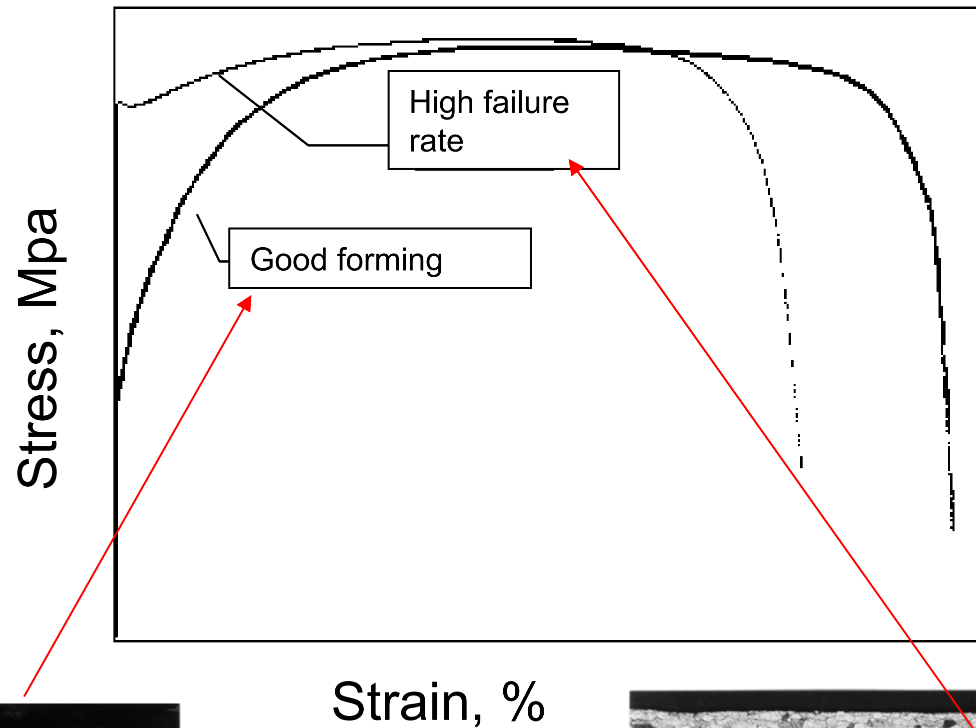
# Recrystallization

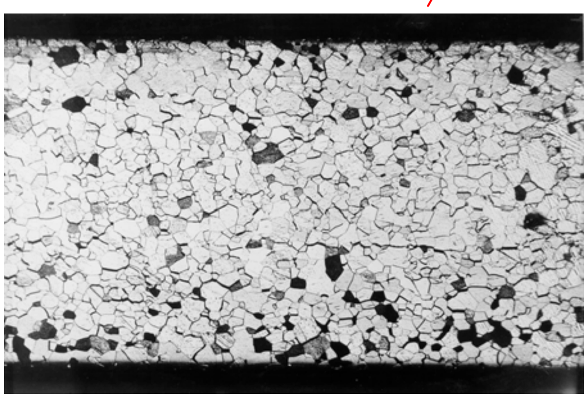
We need recrystallized material

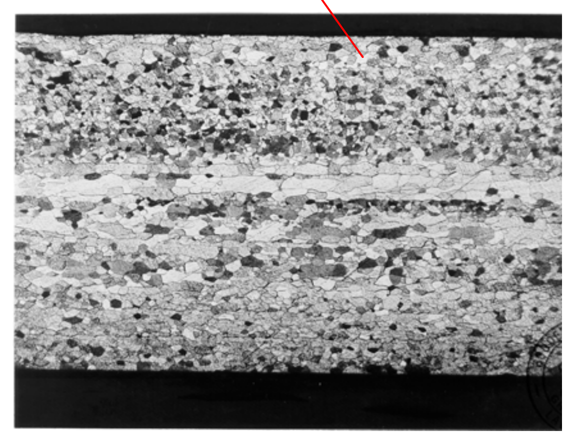
# The grain structure influences the formability

**Therefore the yield strength, σ0,2 is specified for XFEL as**

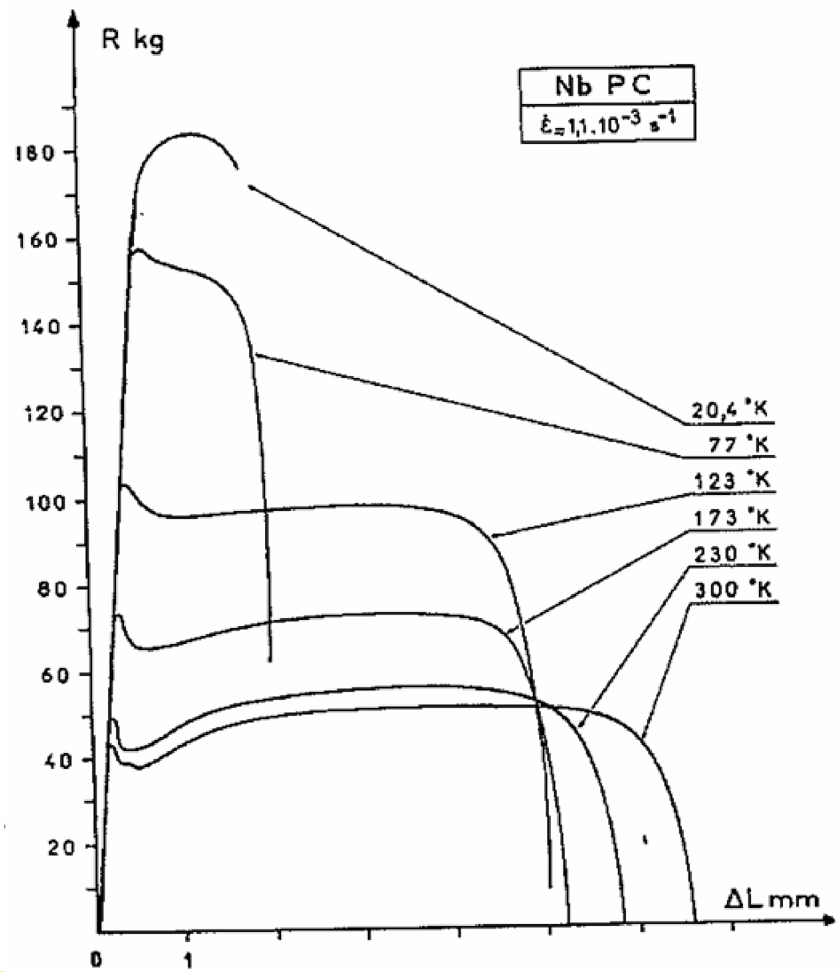
**50<σ0,2<100 N/mm$^2$ (Mpa)**





# Low temperature behavior of Nb

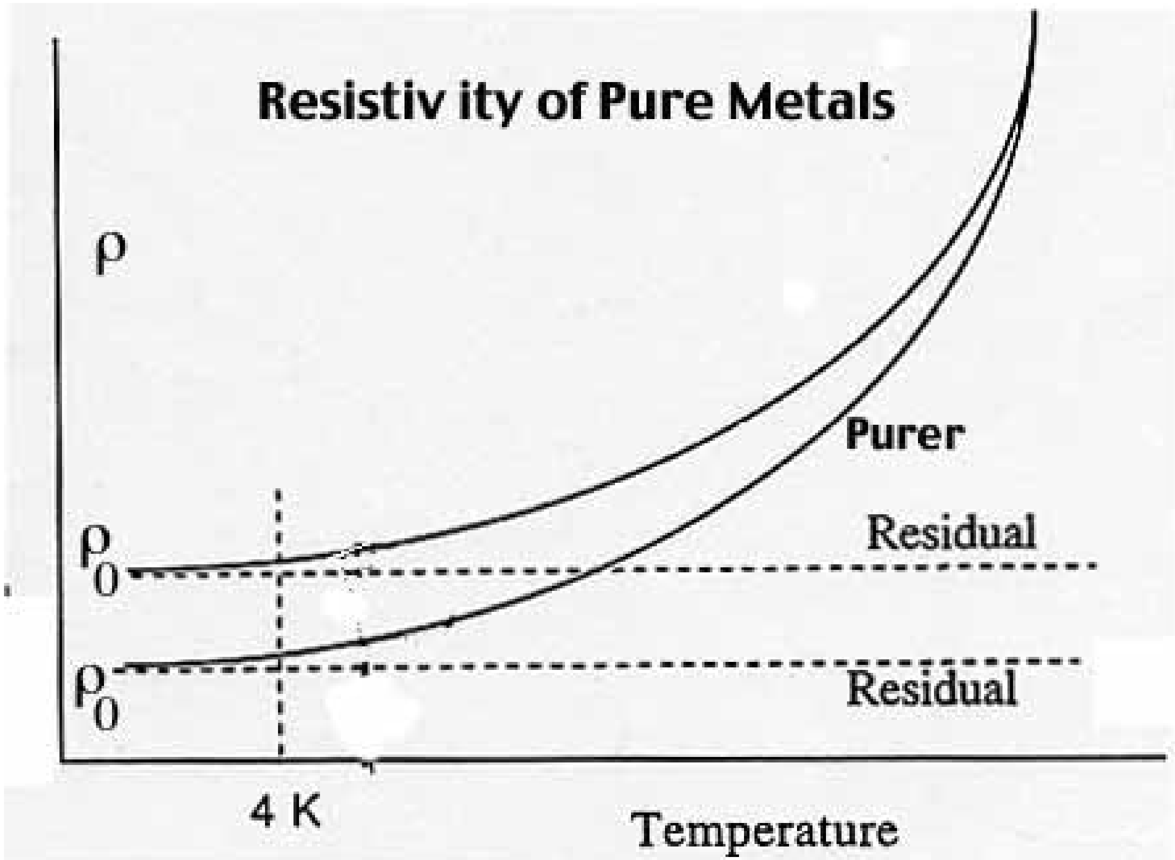



- Yield strength ↑↑ when T ↓
- ductility ↓ (T< 20 K => Nb is brittle )

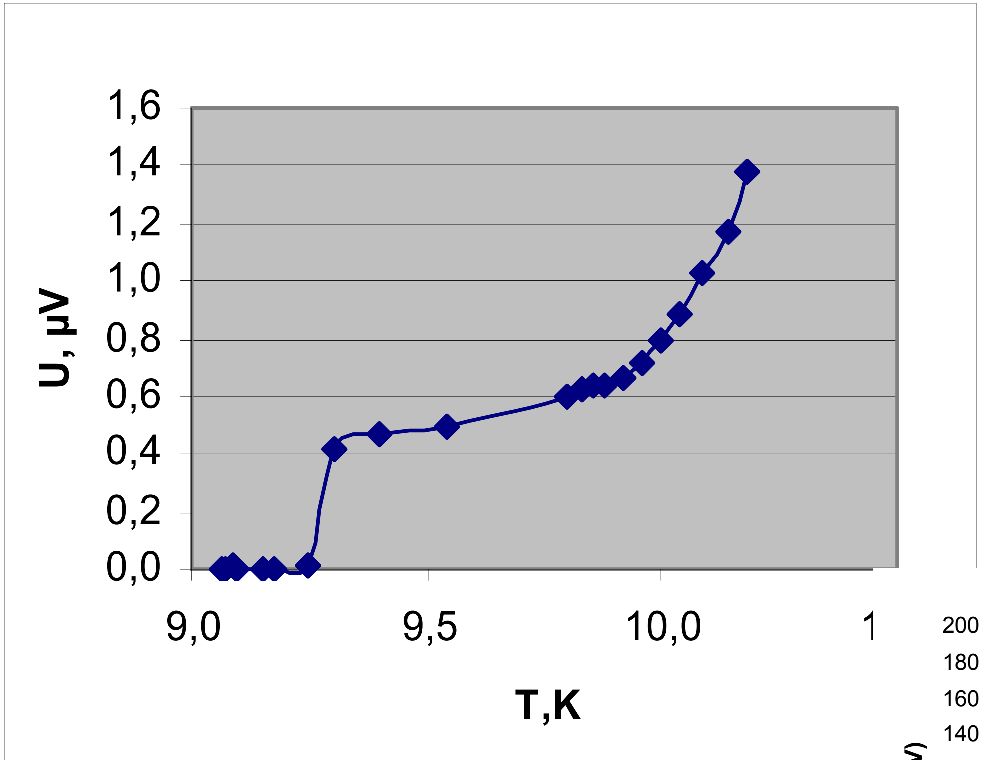
**Material Purity:** Electrical resistivity of metals at low temperatures is an excellent tool to determine impurity concentrations. The residual resistivity at T =0K is caused mainly by scattering of electrons on impurities.

Residual Resistivity Ratio $$RRR = \frac{\rho(295K)}{\rho(4.2K)}$$

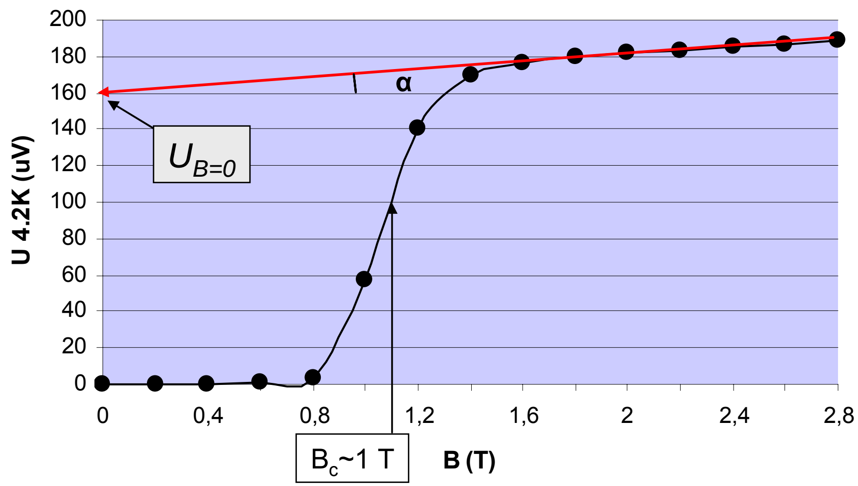
$$\rho(T) = \rho_{res} + \rho_{ideal}(T)$$

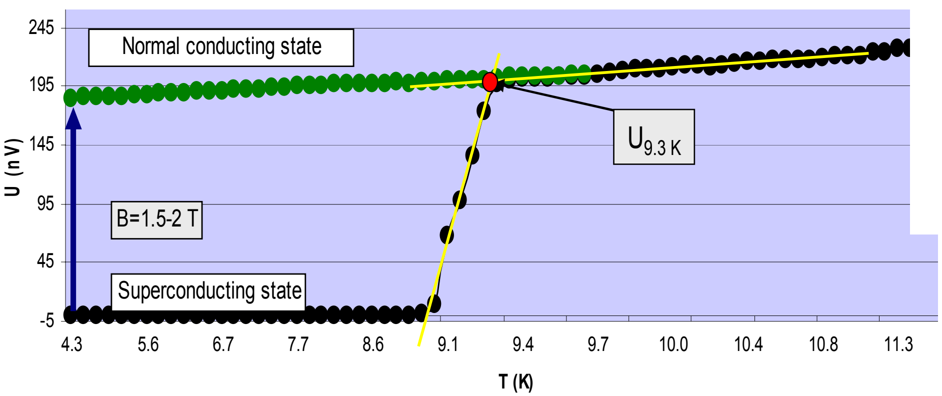



W. Singer. Tutorial. 14th International Workshop on RF Superconductivity, September 20-25, 2009, Dresden, Germany




Temperature dependence of resistivity for superconducting Nb at temperatures close to Tc

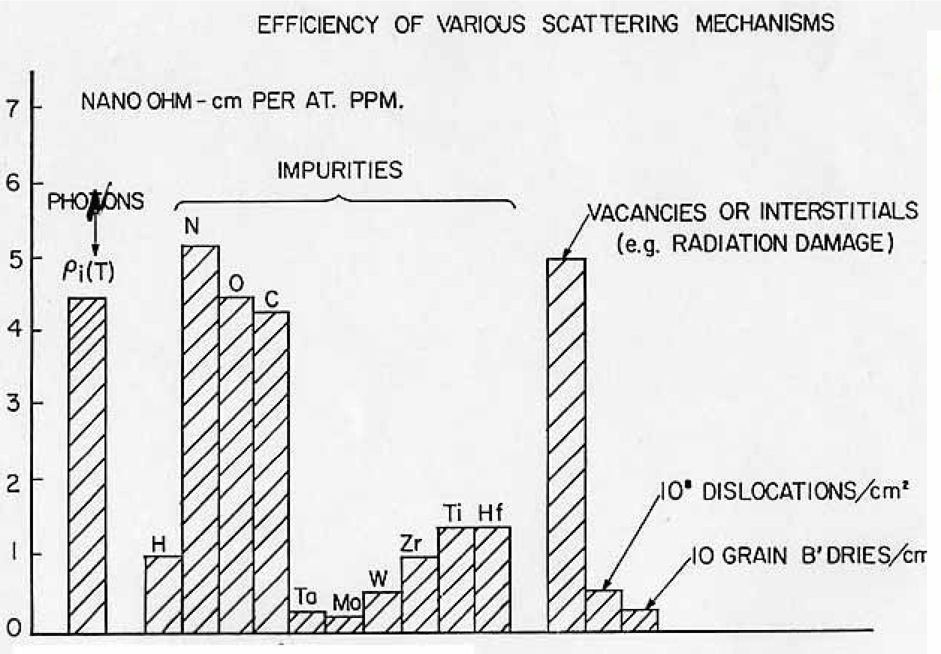


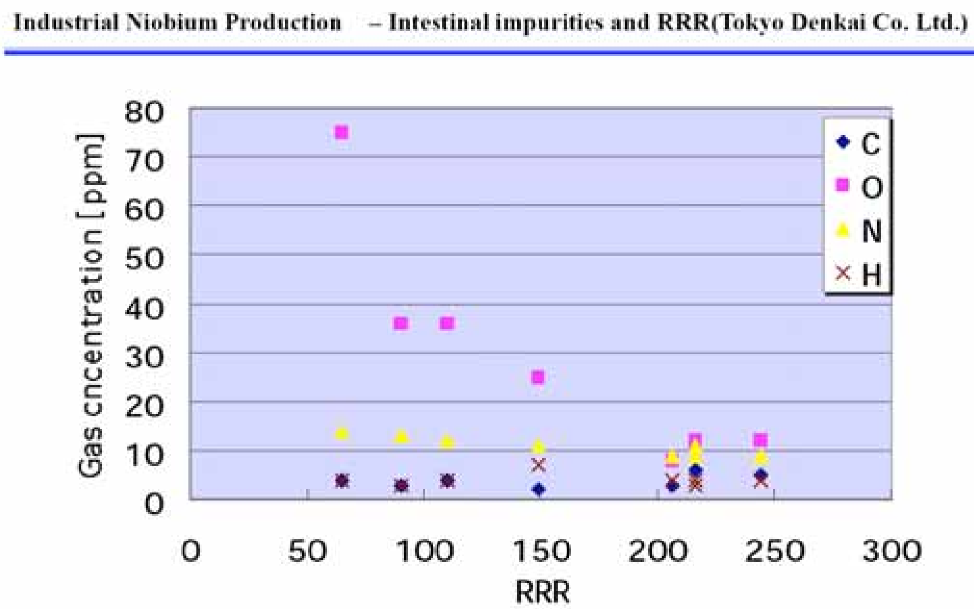




*RRR* determination by magnetic field extrapolation method

DC (direct current) -method: extrapolation of U(T) curve

# Influence of impurities on RRR



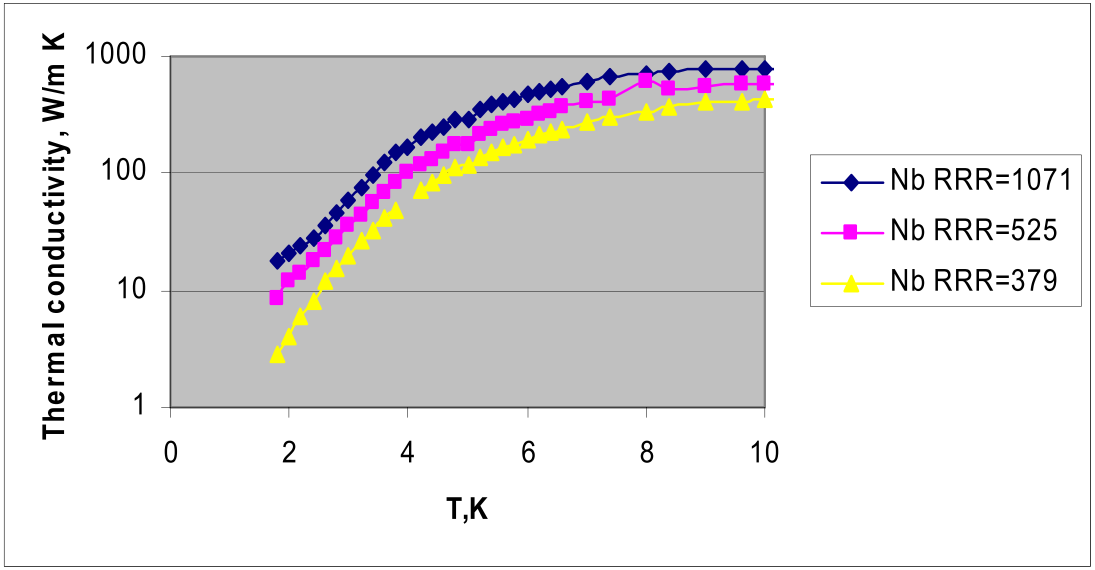



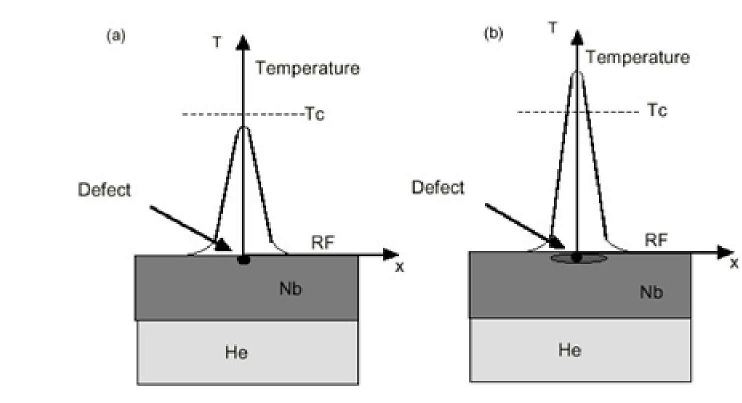

Contribution of different defects in the scattering mechanism (Schulze)

$$RRR = \frac{R(300K)}{R(10K) + \sum_{i=1}^{4} \frac{\partial R_i}{\partial C_i} C_i}$$

R(300K)=1,46.10-5 Ω cm, R(10K)=8,7.10-9 Ω cm, C=1 wt. ppm

Relationship between RRR and nonmetallic impurities measured by Tokyo Denkai




Thermal conductivity of high purity Nb at low temperatures

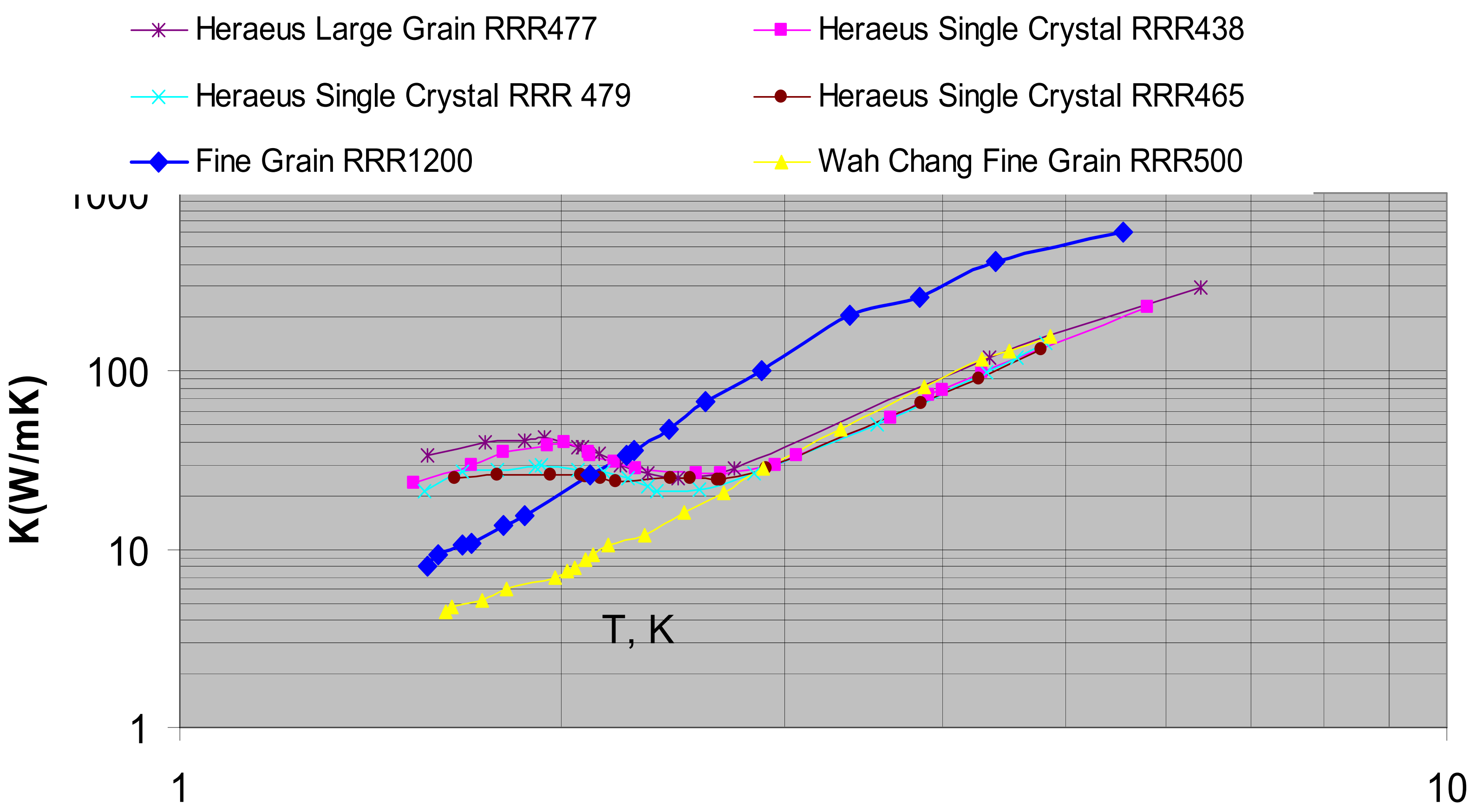
Normal conducting cluster triggers the quench, if the temperature exceeds Tc

Rule of thumb

$$\lambda(4{,}2K) = C \cdot \left({}^{W}\!/_{m \cdot K}\right) \cdot RRR$$

$$C \approx 0{,}25 \div 0{,}14$$

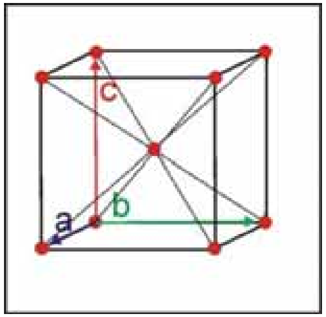
$\lambda_T \approx$ RRR $\approx$ purity




**Thermal conductivity** of single crystal and polycrystalline niobium.

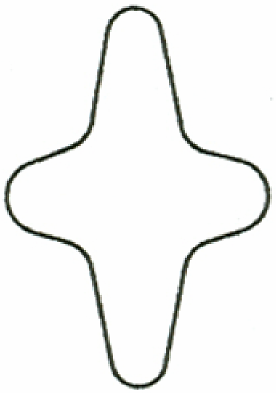
Phonon peak is clearly pronounced for single crystals.

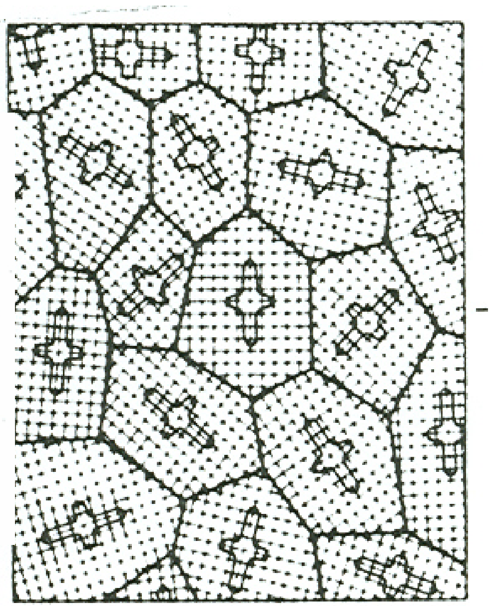
$$\lambda(T, RRR, G) = R(y) \cdot \left[ \frac{\rho_{295K}}{L \cdot RRR \cdot T} + a \cdot T^2 \right]^{-1} + \left[ \frac{1}{D \cdot \exp(y) \cdot T^2} + \frac{1}{B \cdot G \cdot T^3} \right]^{-1}$$

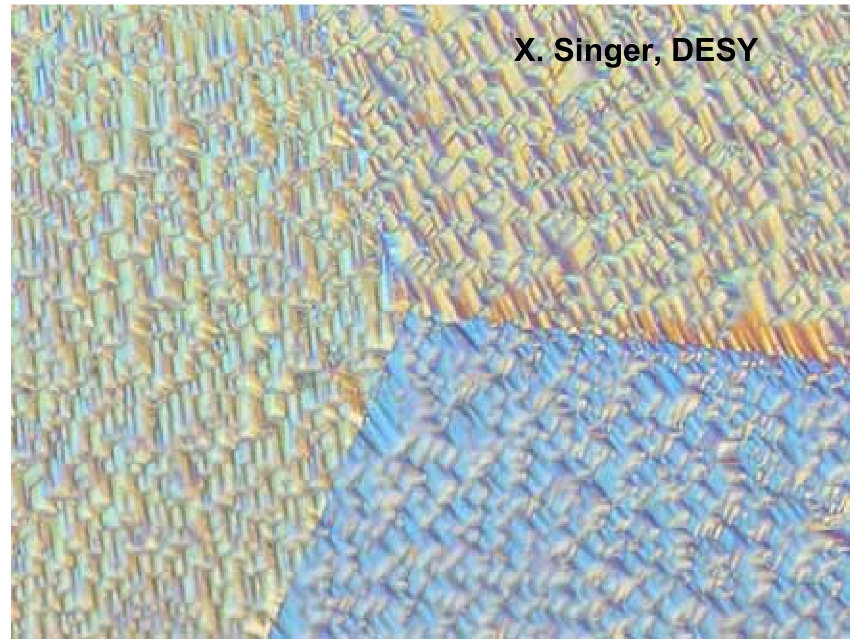



bcc lattice (body centered cubic)

# Texture





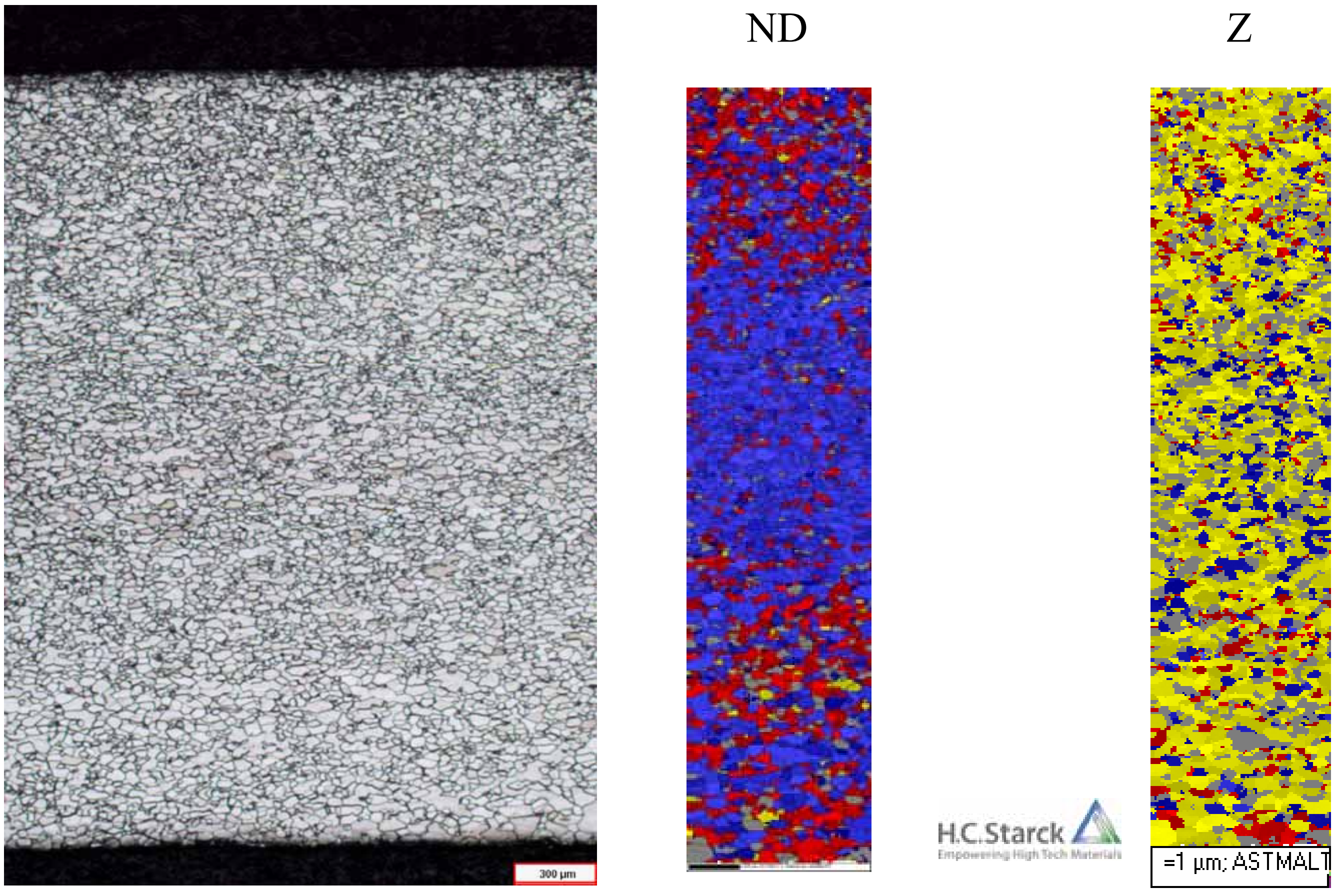



The anisotropic properties of a material is the average of anisotropic properties of its crystallites

Microstructure of the three grains of Nb after proper etching (optical microscope). The crystal lattice in neighboring grains is the same (bcc) but has a different orientation

# TEXTURE BY EBSD ELECTRON BACK-SCATTERING DIFFRACTION

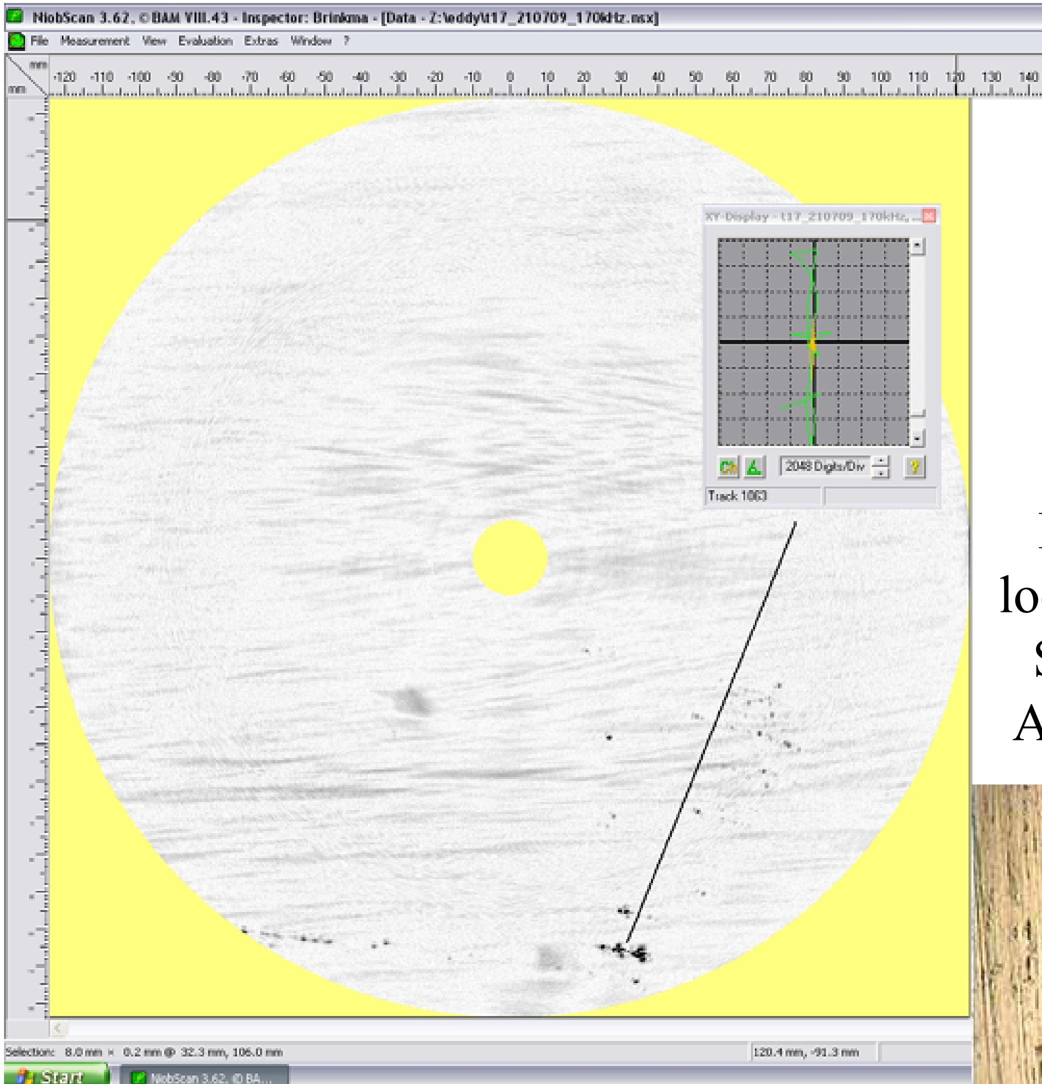
3 mm Nb sheet



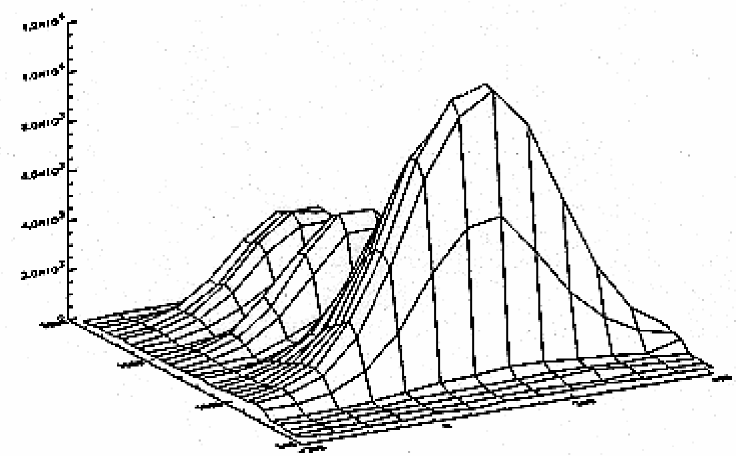

Electron back scattering diffraction EBSD

Niobium sheet after annealing. Colors refers to crystal orientations (orientation image)

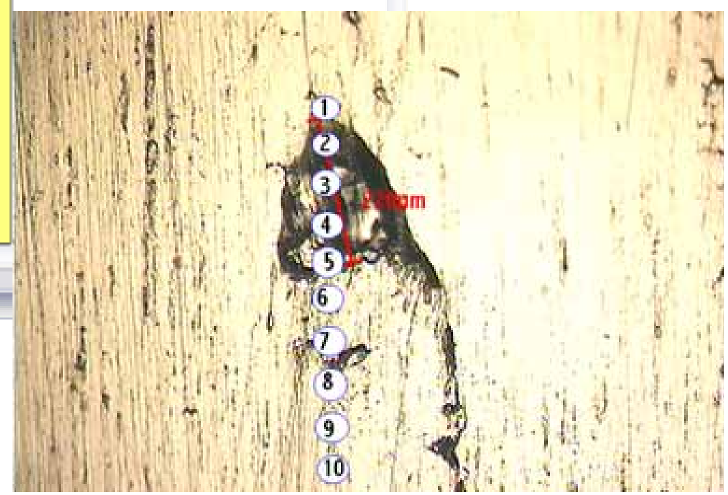
# Local defects




Iron particles, probably imbedded during rolling T17

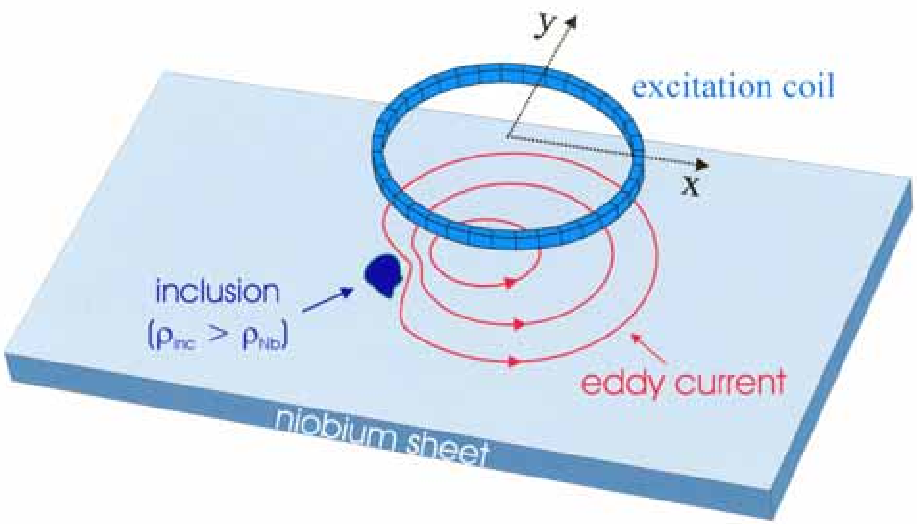


Iron signal distribution in one of the locations of the Nb sheet T17 measured Synchrotron Radiation Fluorescence Analysis (SURFA) and defects image.



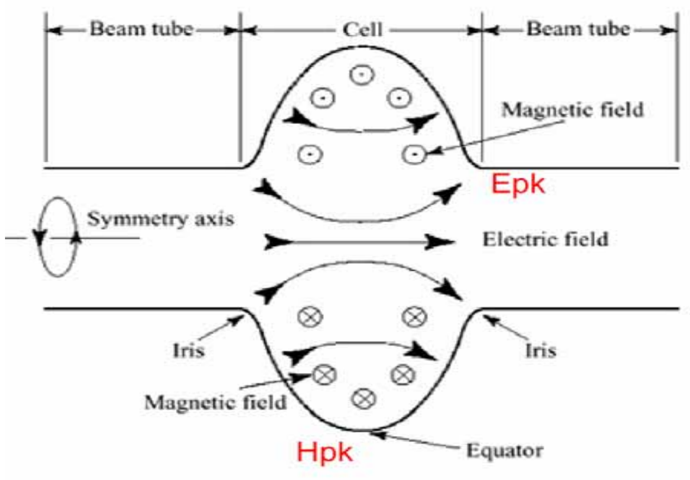
# Search for clusters in Nb sheets.
# Eddy current system.


DESY eddy current scanning apparatus for niobium discs. 100% Nb sheets for TTF scanned and sorted out. **Feed back to Nb producer was very important**

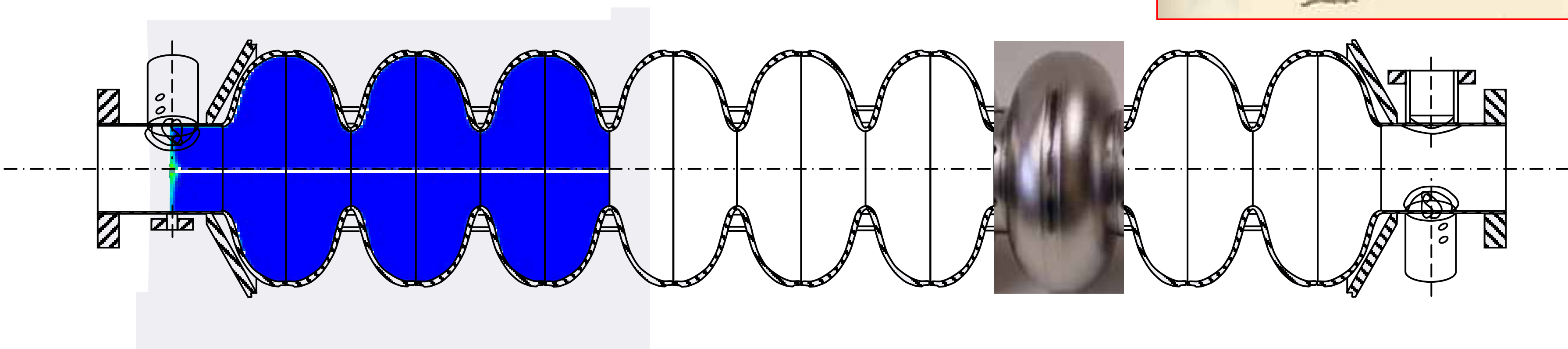



Principle of eddy current measurement

# Fabrication







**Frequency 1.3 GHz**

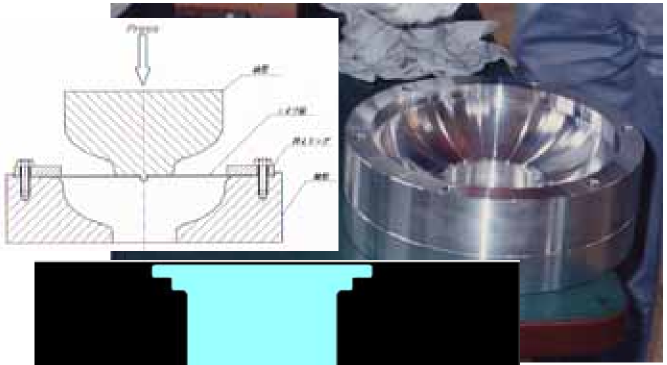
**High purity niobium RRR 300**

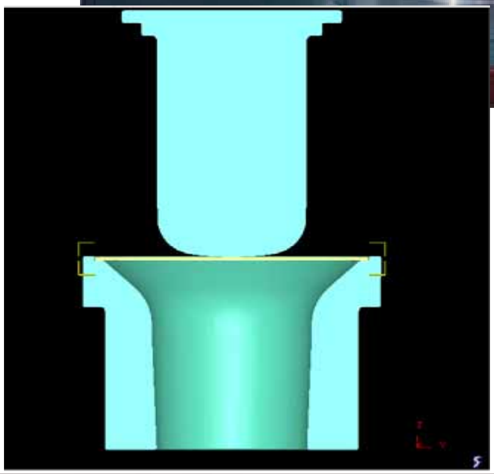
**Deep drawn from sheets**

**Welding with electron beam**

**Operating temperature 2K**

# Experiences of ca. 20 years of industrial cavity fabrication by deep drawing and EB welding are available

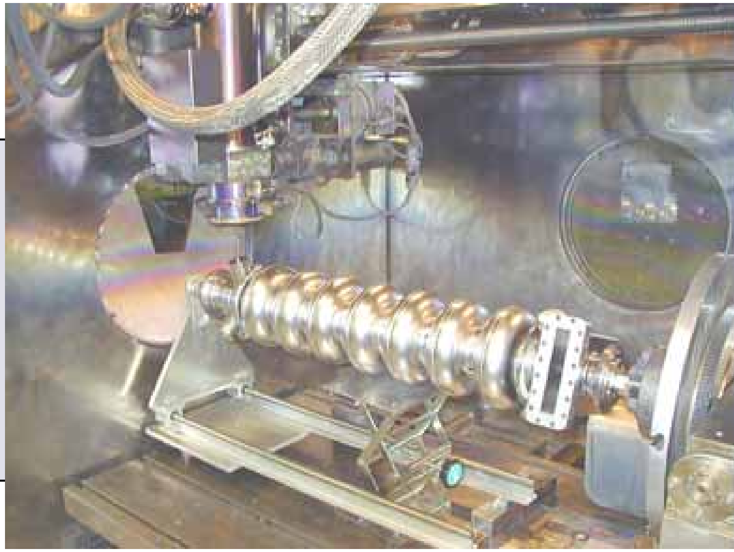




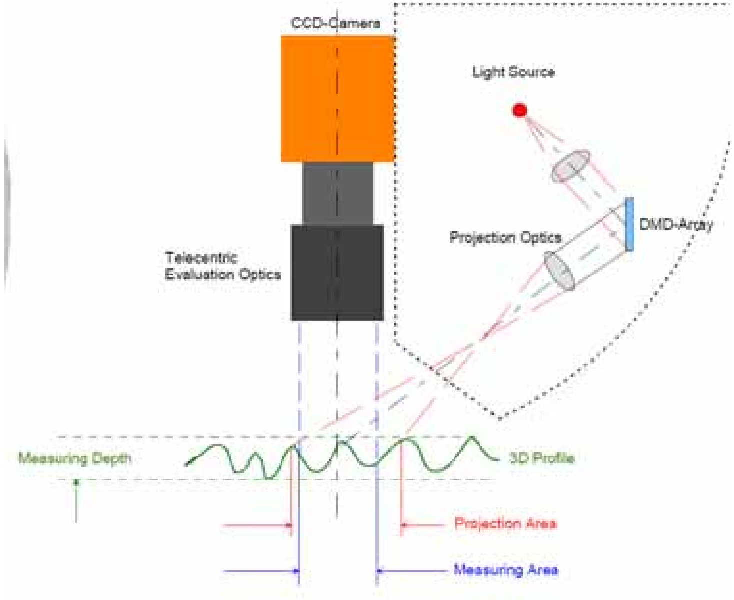
**Half cells** are produced by **deep drawing**.

Dumb bells are formed by **electron beam welding**.

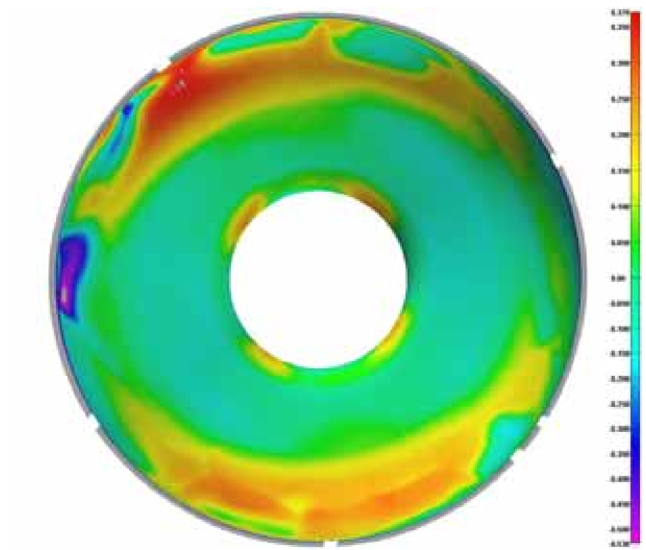
After proper **cleaning** eight dumb bells and two end group sections welded by electron beam together

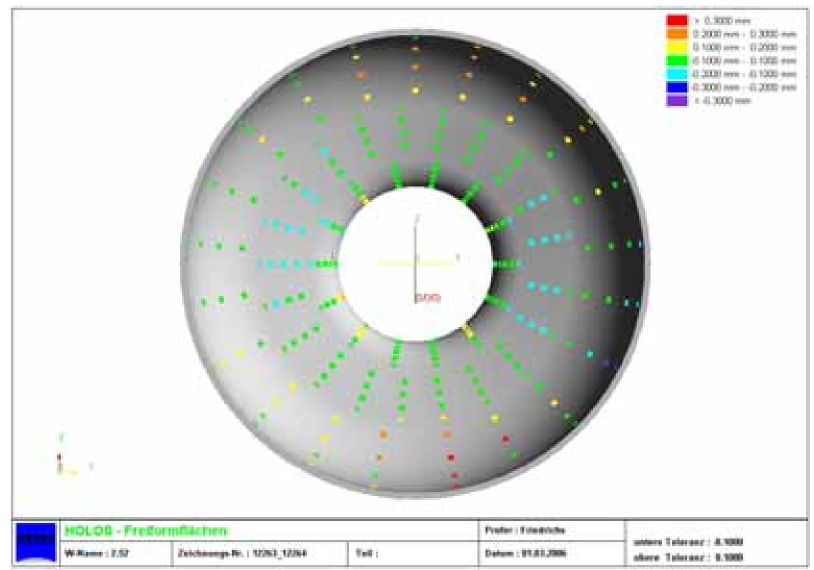


**Important: clean conditions on all steps shape accuracy, preparation and EB welding**










**Shape accuracy:** Optical and mechanical 3D measurement of the half cell shape

# Frequency and length adjustment

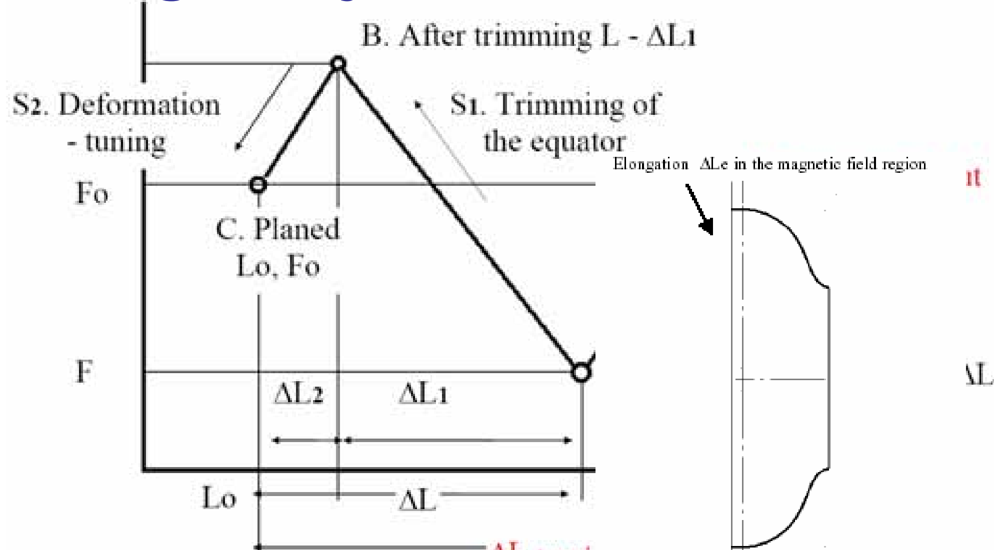
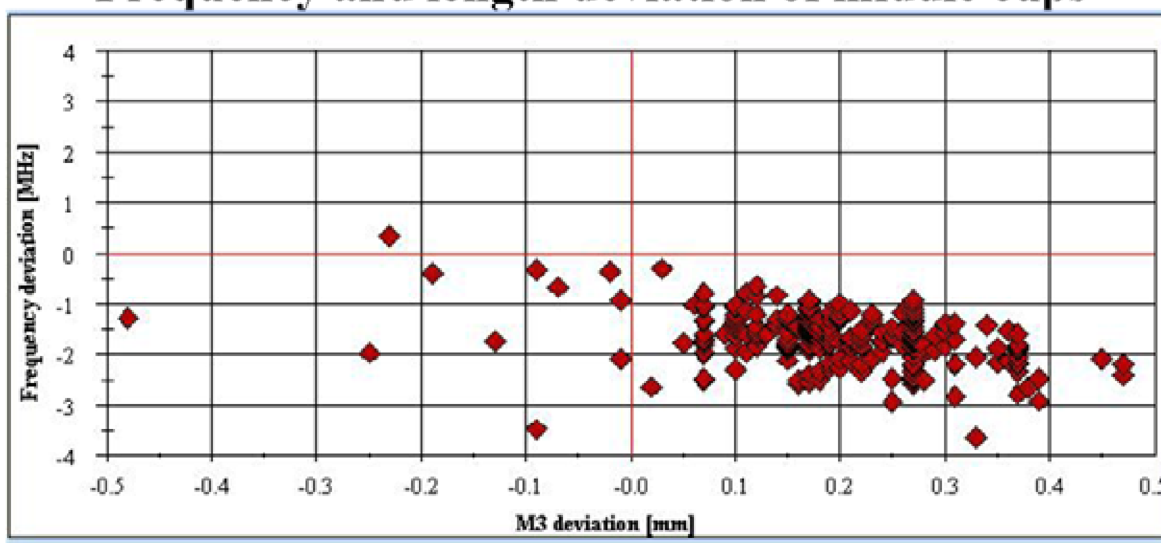
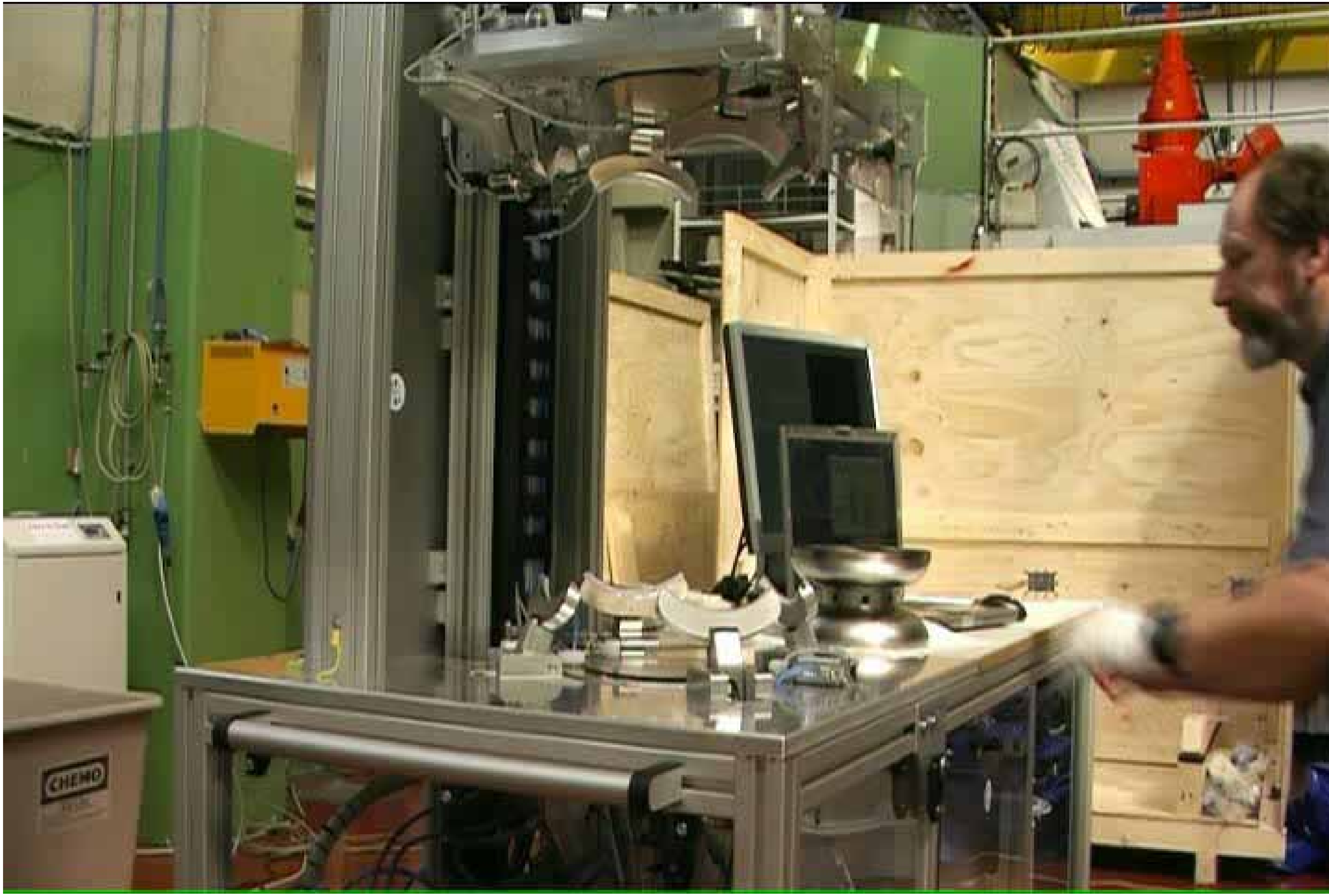



Figure 3: Trimming of the equator to adjust the elongation at the equator

**Frequency and length deviation of middle cups**

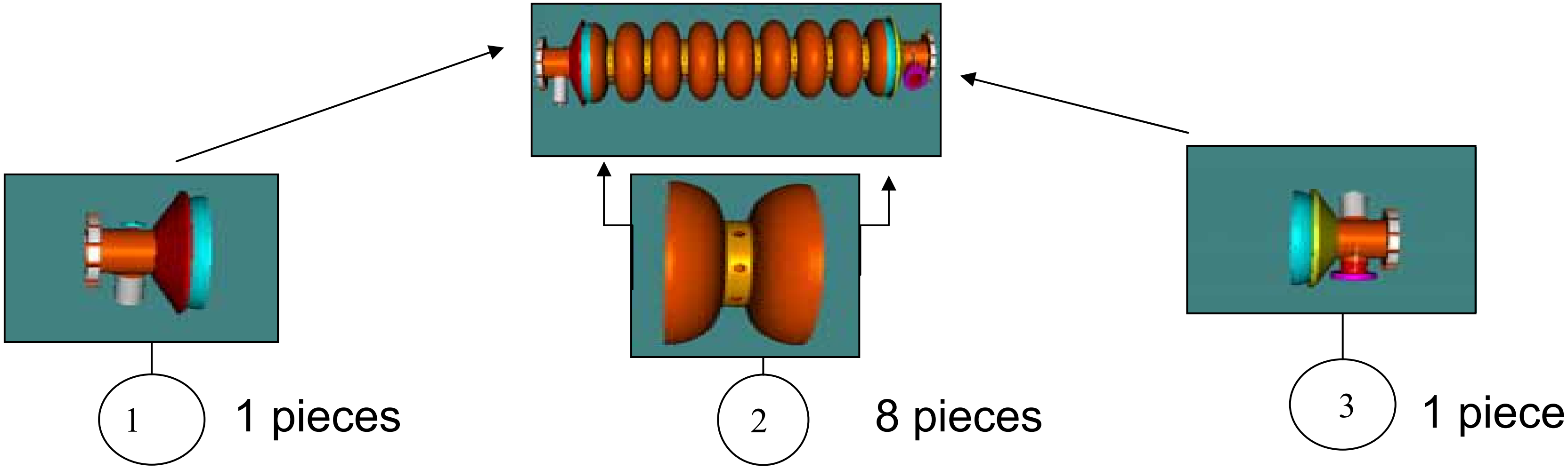



Wah Chang (EDMS-DB)



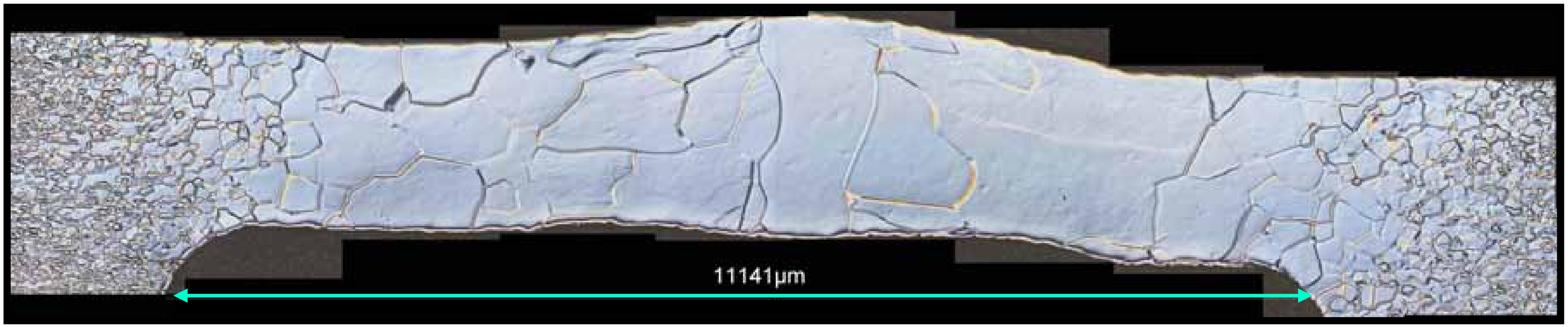

Equipment for RF measurement on half cells and dumb bells HAZEMEMA is developed at DESY for XFEL fabrication (SRF2009, Poster THPP0071)

# Cavity welding: the general way
# There are differences of welding processes in industry



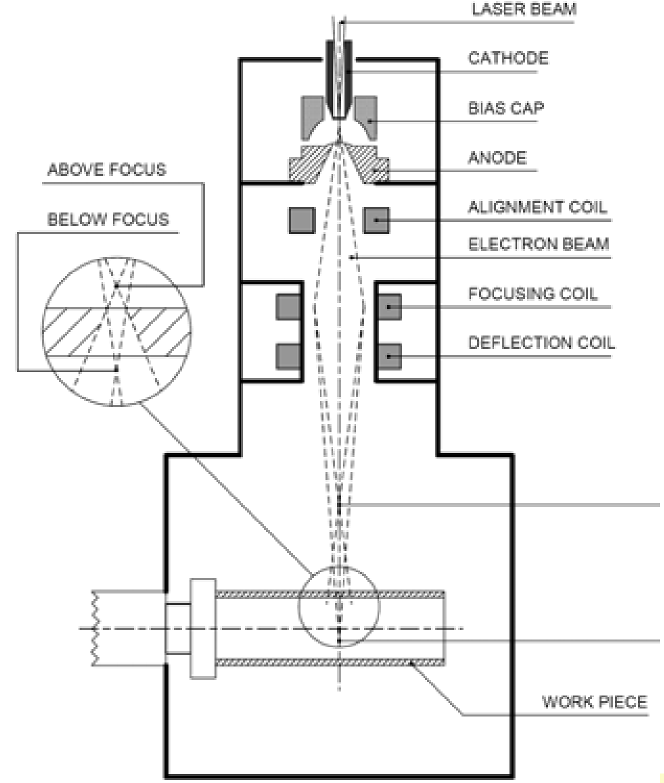

1. Degreasing and rinsing of parts
2. Drying under clean condition
3. Chemical etching at the welding area ( Equator)
4. Careful and intensive rinsing with ultra pure water
5. Dry under clean conditions
6. Install parts to fixture under clean conditions
7. Install parts into electron beam (eb) welding chamber
   ( no contamination on the weld area allowed)
8. Pump down to vacuum in the EBW chamber $E^{-5}$ mbar
9. Welding and cool down of Nb to T< 150° C, venting
10. Leak check of weld

# Electron Beam Welding EBW



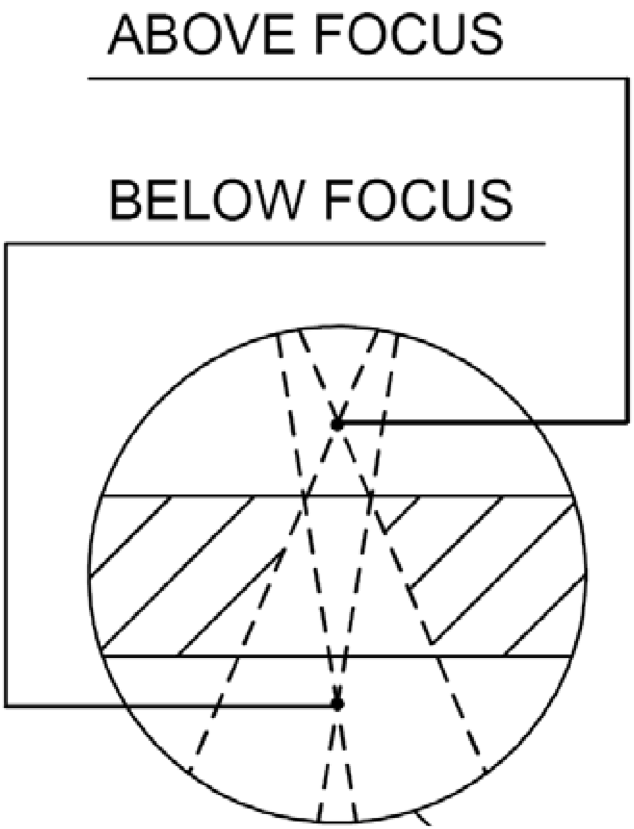

Microstructure of the EB welding area. The grain size
G=50 ÷ 2000 µm

# Electron Beam Welding Machine

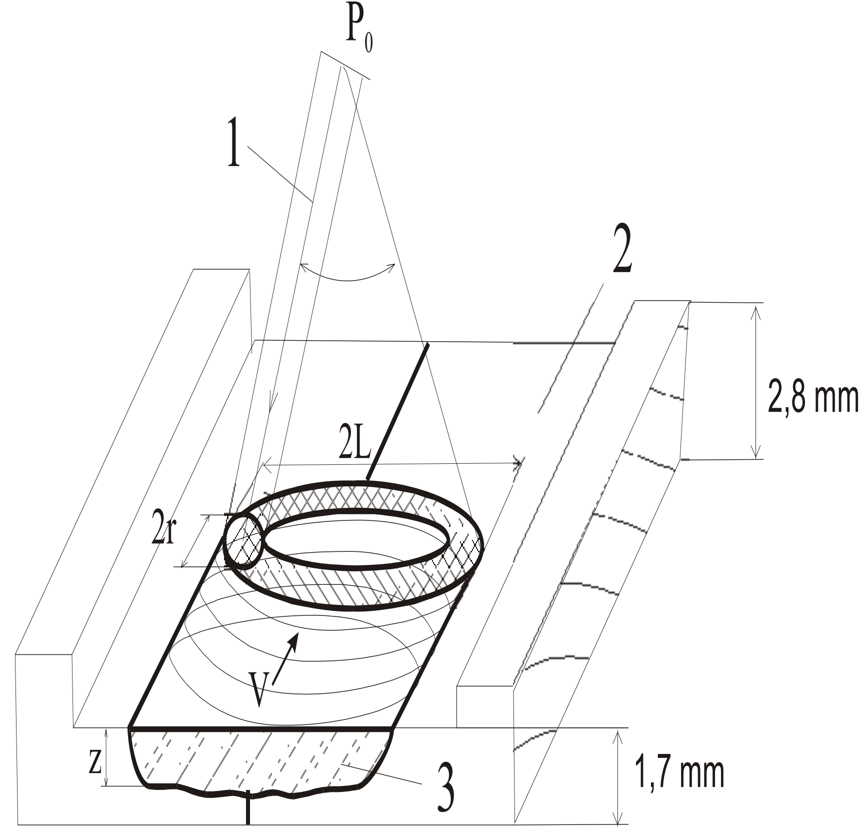




**Specification of DESY Electron Beam Welding Machine**

**Voltage: 70 - 150 kV**
**Beam power: max. 15 kW**
**Beam current: 0 bis 100 mA**
**Chamber size: 3300mm x 1400mm x 1600mm (ca. 7,4 m³)**
**Vacuum: > $5x10^{-6}$ mbar (ca. $2x10^{-8}$ mbar)**
**Pumping time: ca. 20 min =$3x10^{-6}$ mbar**
**2 Cryogenic - Pumps: ca. 2 × 10.000 l/s**
**Displacement along the X-Axes ca. 1400 mm**

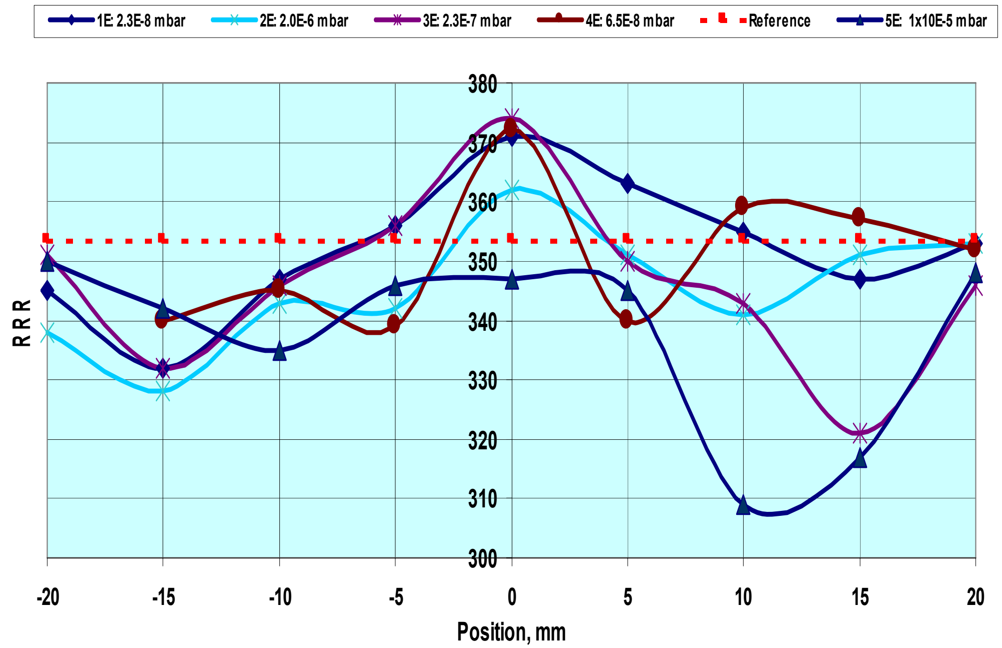



Focusing possibilities
(above focus; below focus)



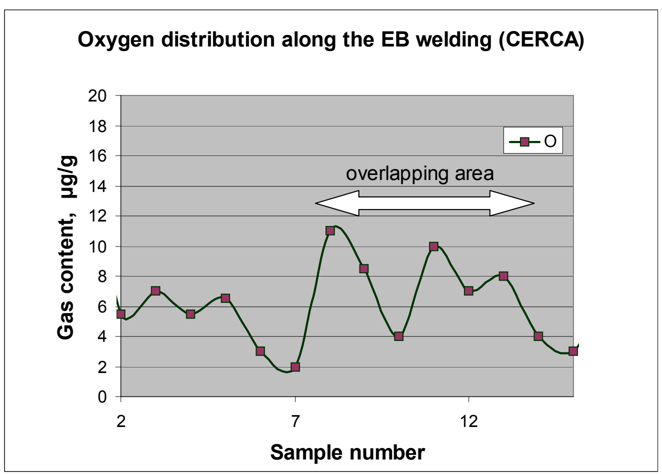

Welding Scheme (circular raster)
1-Electorn beam ($P_0$-power of the beam, r-spot radius on the surface, L- scanning amplitude, V- velocity of the beam movement), 2-Nb sheet, 3- melting zone (z-depth of the melting zone).

# RRR degradation



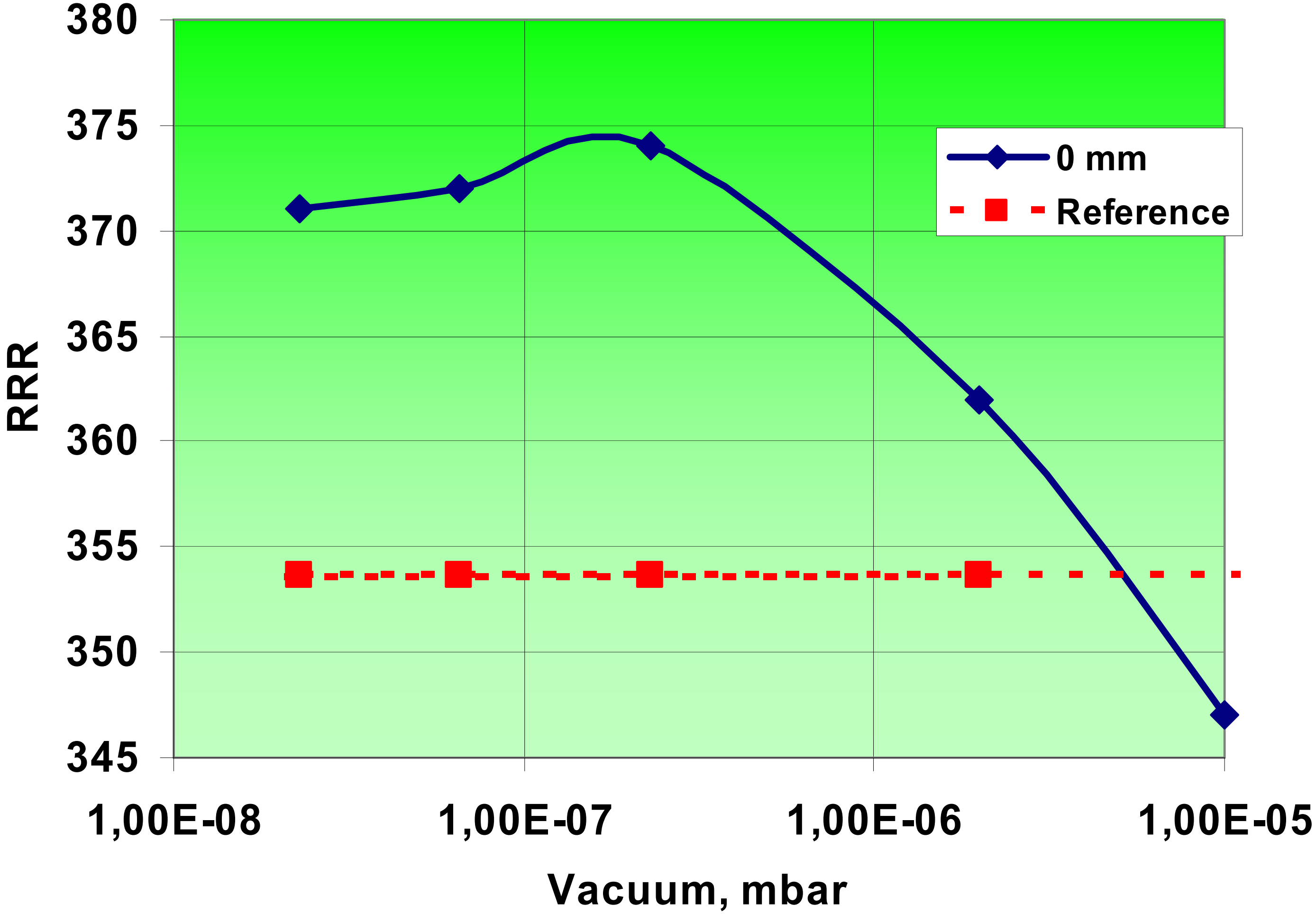

The RRR degradation can take place in the welding seam itself, but also in the thermally affected area and overlapping

RRR in the EB welding area versus distance from the welding seam at different pressures of DESY EB facility




Oxygen distribution along the welding seam. RRR= 280 in the welding seam and RRR= 207 in the overlapping.

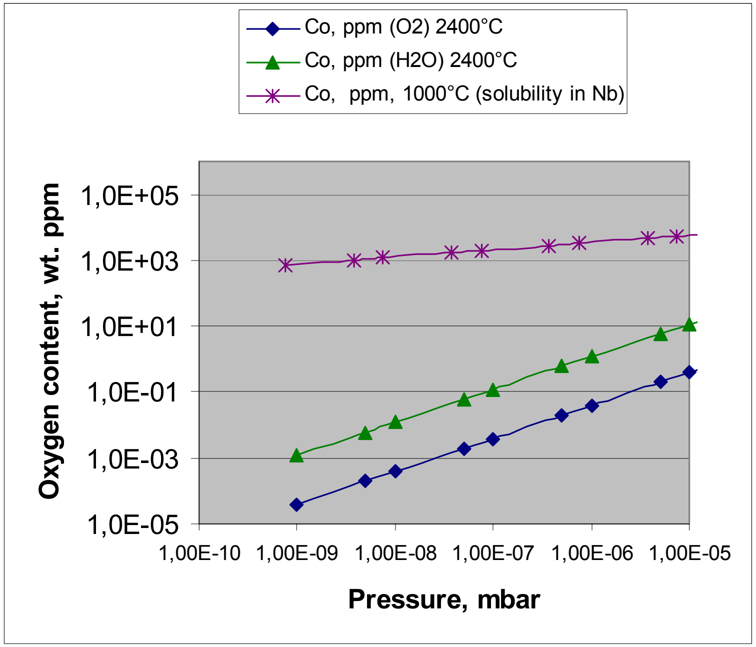
# Electron beam welding of niobium




RRR in the welding seam versus pressure in the welding chamber

**The RRR degradation at welding seam started since pressure of ca. 10-5 mbar.**

# Does the refining or pollution take place during EB welding? Pressure – concentration isotherms of oxygen solubility in Nb in steady state condition




$$C_{o_2}[wt.ppm] = P \cdot 6.9 \cdot 10^{-6} \cdot \exp(4.82 \cdot 10^4 / T) \cdot 10^2$$

$$C_{H_2O}[wt.ppm] = P \cdot 8.55 \cdot 10^{-6} \exp(4.52 \cdot 10^4 / T) \cdot 10^2$$

$$LogC_{o,\alpha-Nb}[wt.ppm] = 0{,}5 \cdot \log P_{o_2} - 7{,}46 + 20050 / T$$

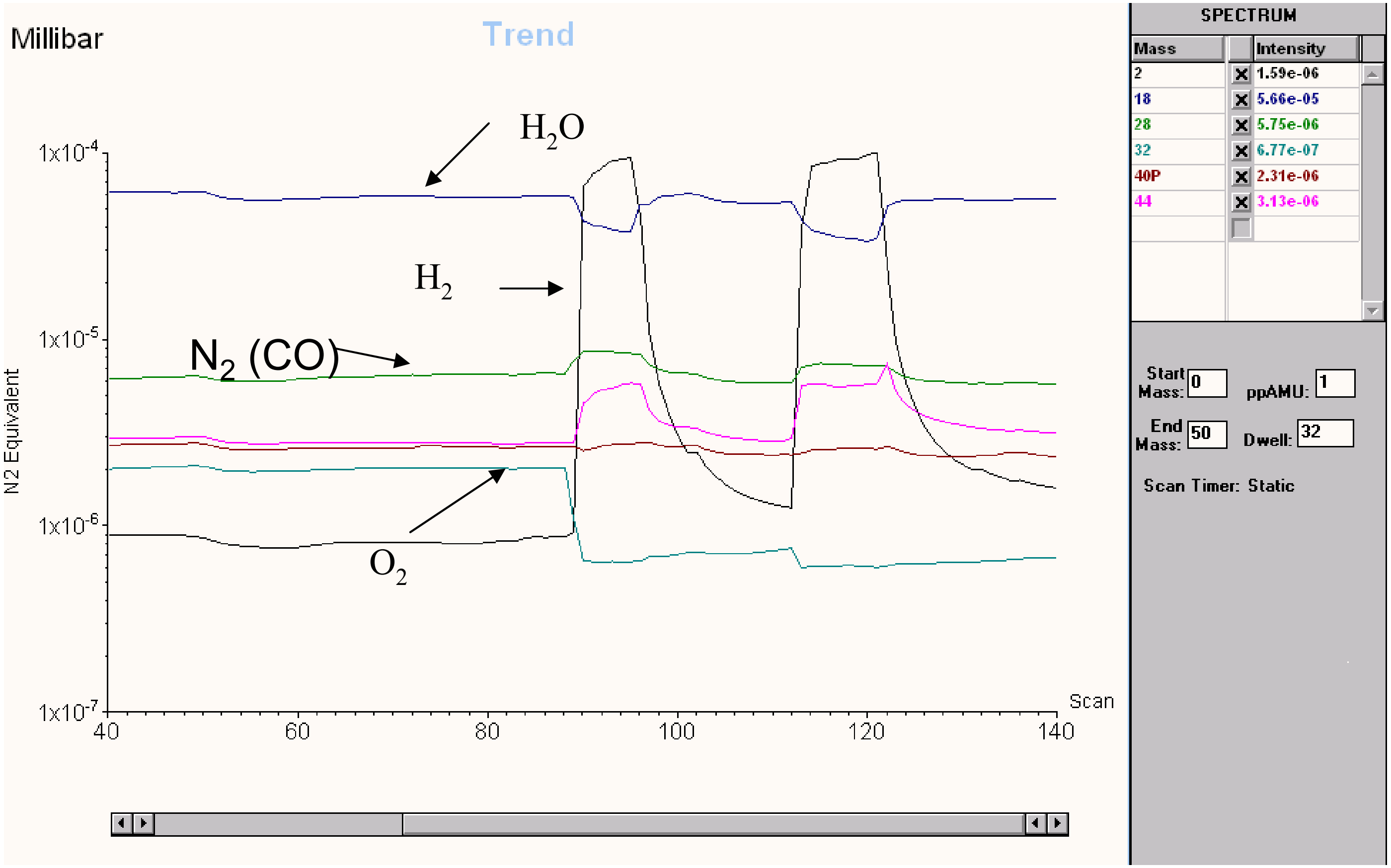
*E.From, H.Jehn*

Kinetic of process is of grate importance

$$\Delta C \approx \frac{1}{2} \cdot p \cdot \frac{t}{d}$$

***For concentration change $\Delta C$ of 4 wt. ppm, sample thickness d=2 mm, equilibrium pressure p=$10^{-6}$ mbar the degassing time is t=800 sec.***

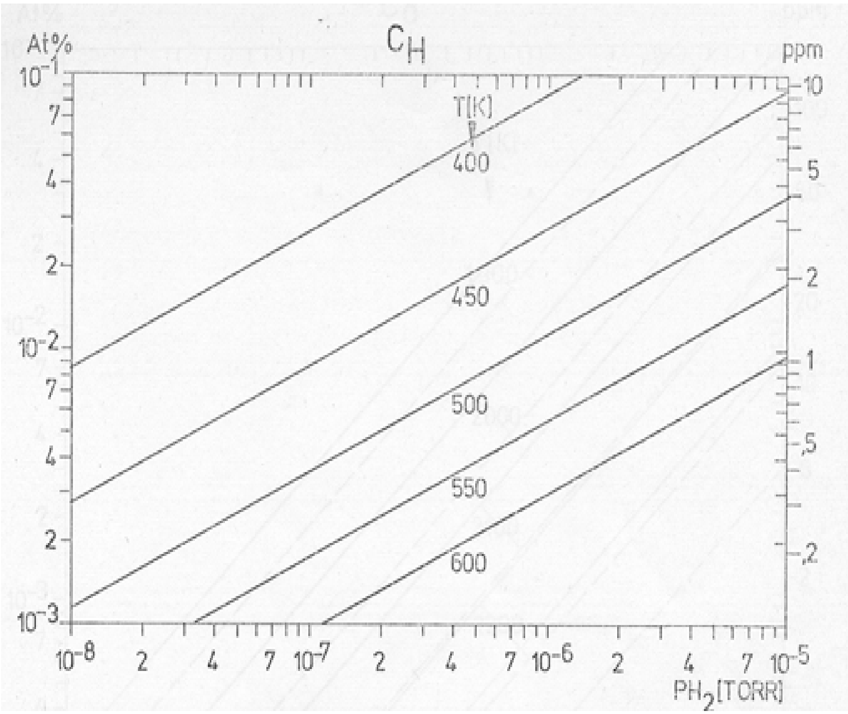
# Partial pressure in the EB chamber during welding of Nb300 sample



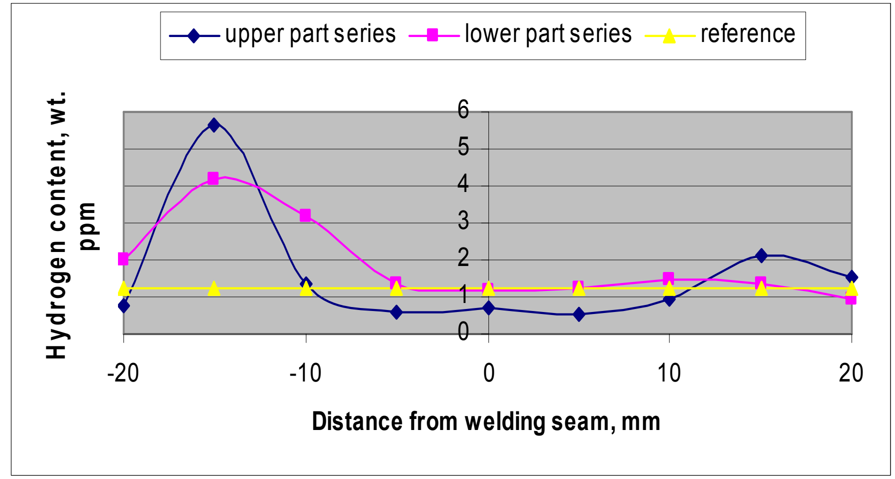

- **Water decomposition during welding**
- **Hydrogen from water and due to degassing**
- **Oxygen uptake**

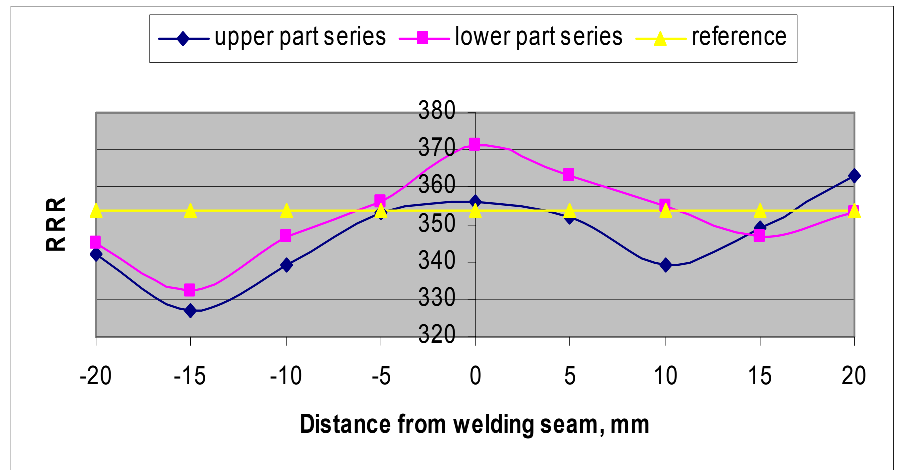
**Temporal changes of gas partial pressure in vacuum chamber during the EB welding process.**

# Correlation of hydrogen content and RRR at ultra high vacuum




Pressure – concentration isotherms of hydrogen in Nb in steady state condition

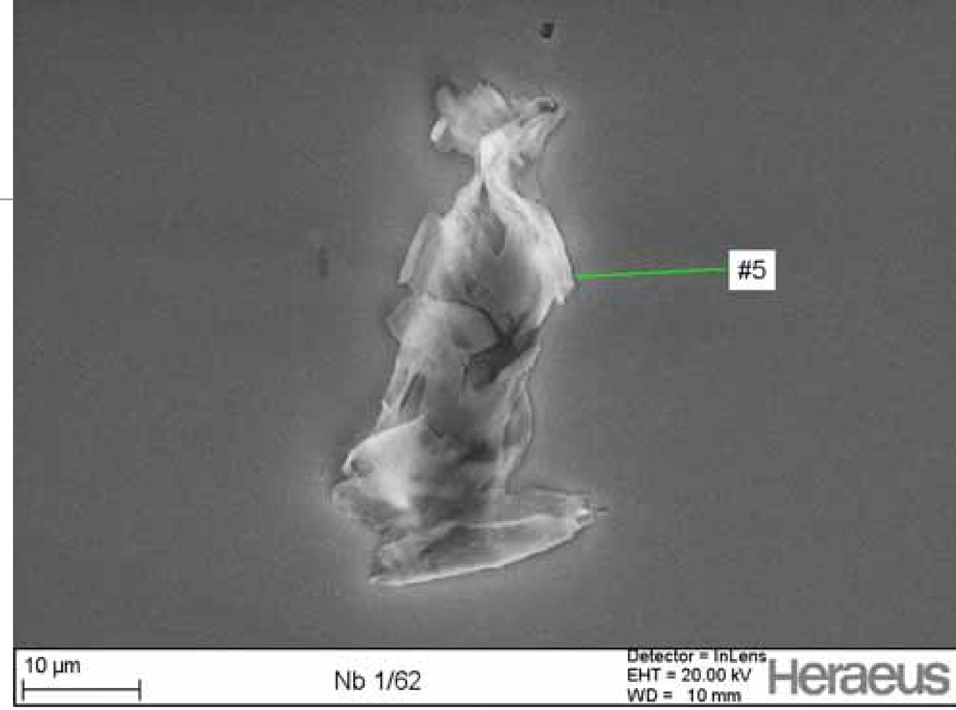



Absorption of hydrogen can take place at the area with moderate temperatures

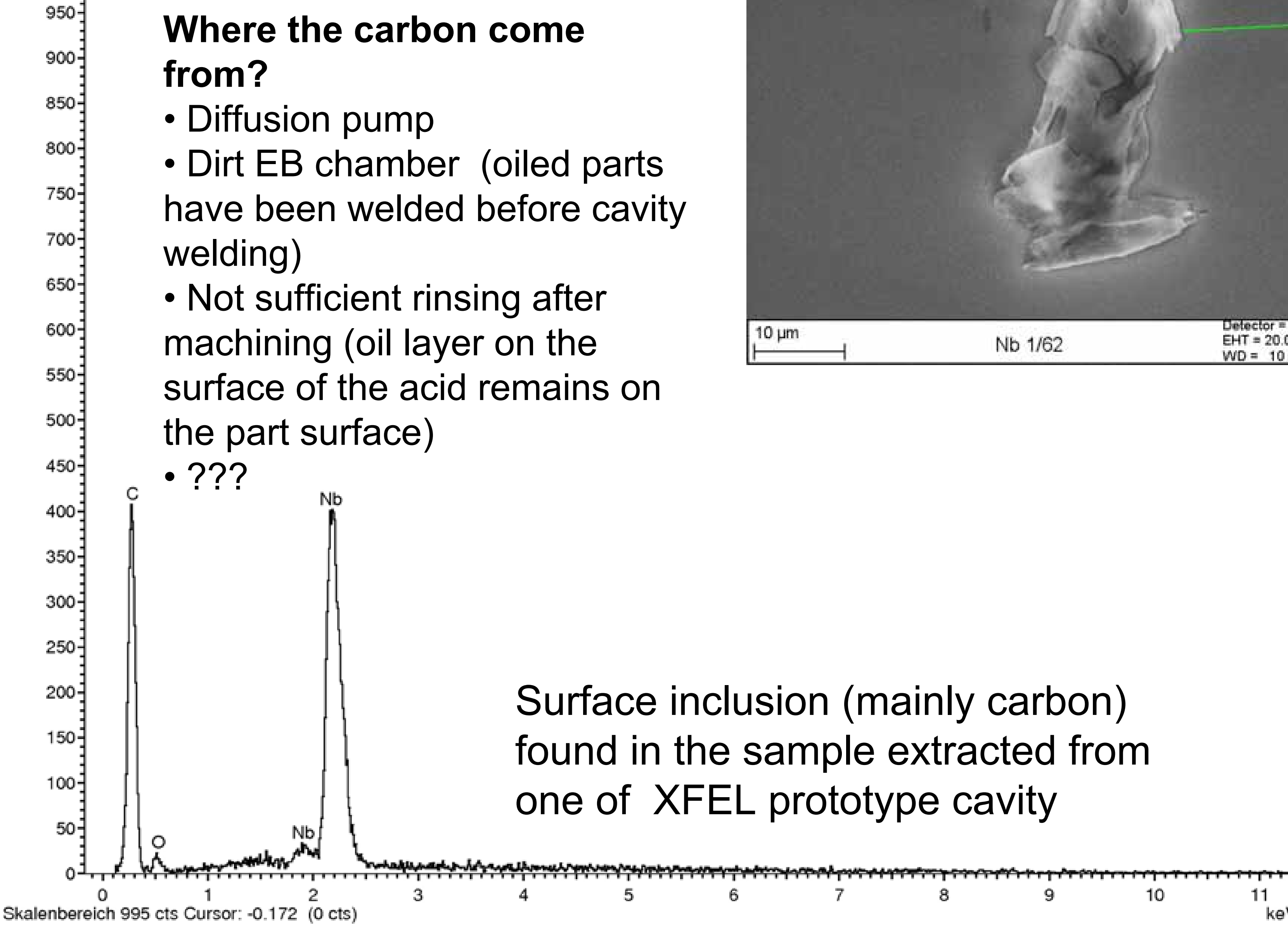
Comparison of RRR and hydrogen content in welding area (pressure $2.3 \times 10^{-8}$ mbar)

# Clean conditions are essential. Example: C (carbon) on the inside cavity surface even after EP



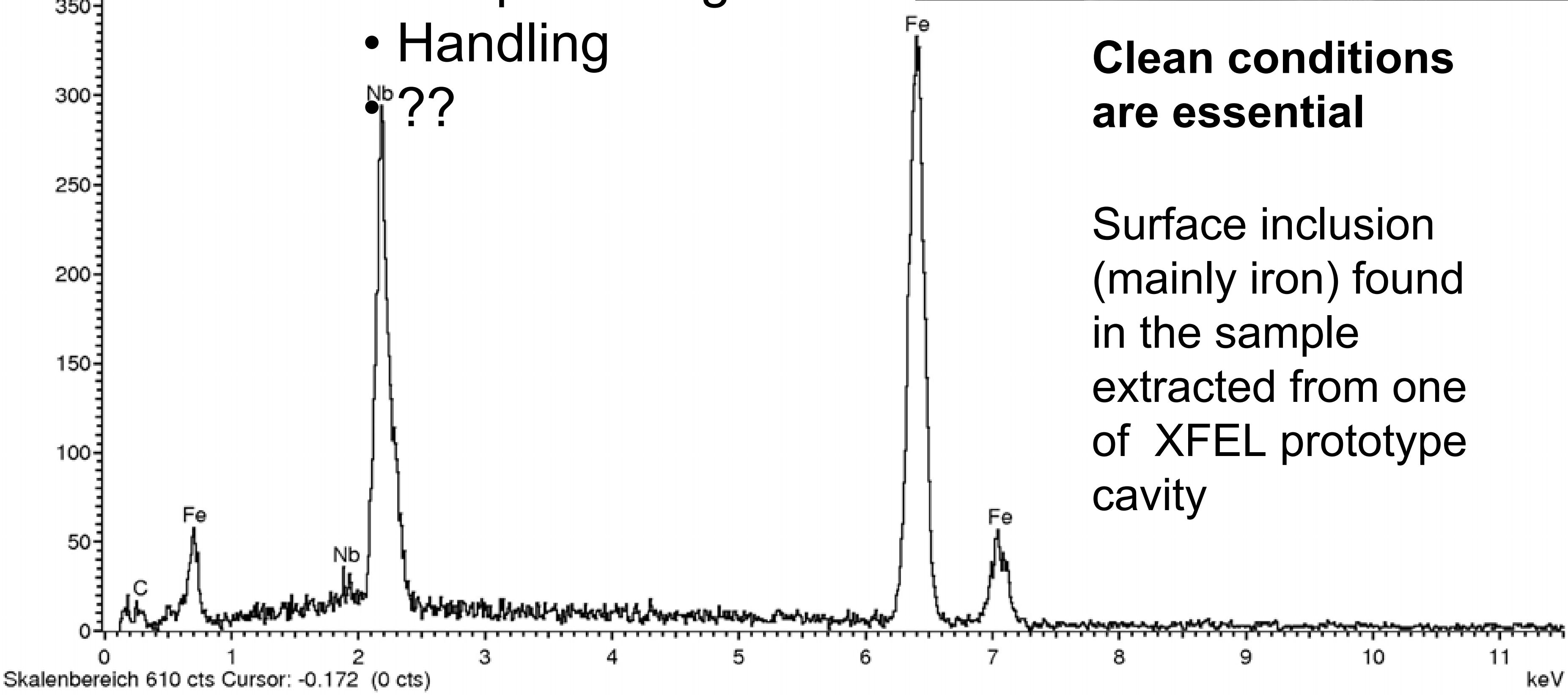

**Where the carbon come from?**

- Diffusion pump
- Dirt EB chamber (oiled parts have been welded before cavity welding)
- Not sufficient rinsing after machining (oil layer on the surface of the acid remains on the part surface)
- ???



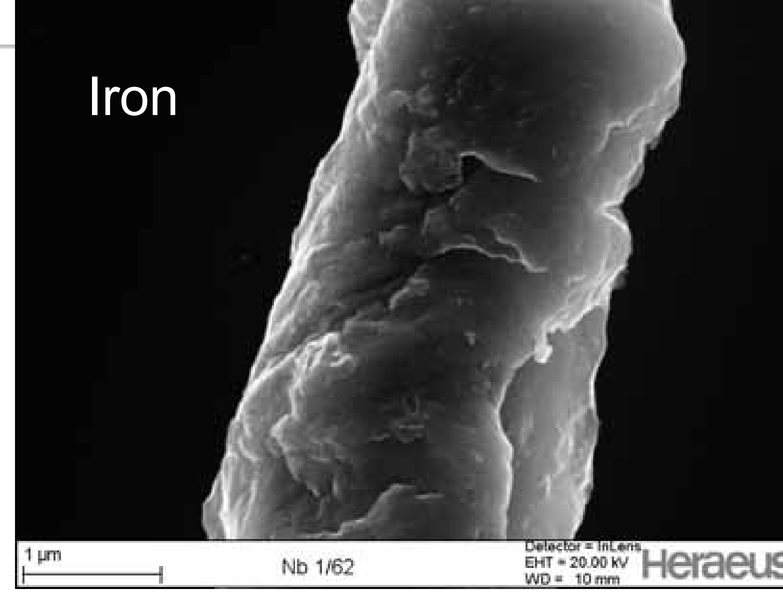

Surface inclusion (mainly carbon) found in the sample extracted from one of XFEL prototype cavity

## Example Fe (iron)



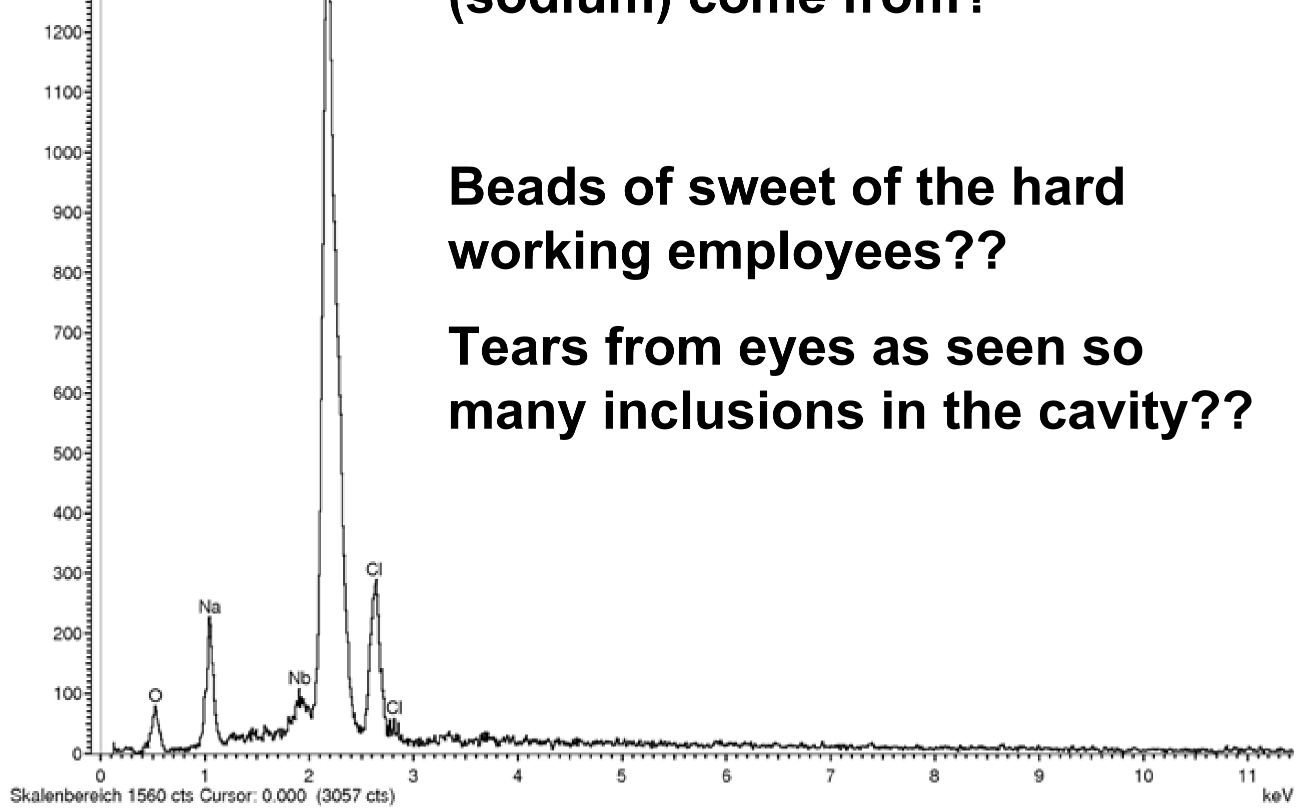

**Where the Iron come from?**

- Nb sheet fabrication
- Deep drawing
- Handling
- ??




**Clean conditions are essential**

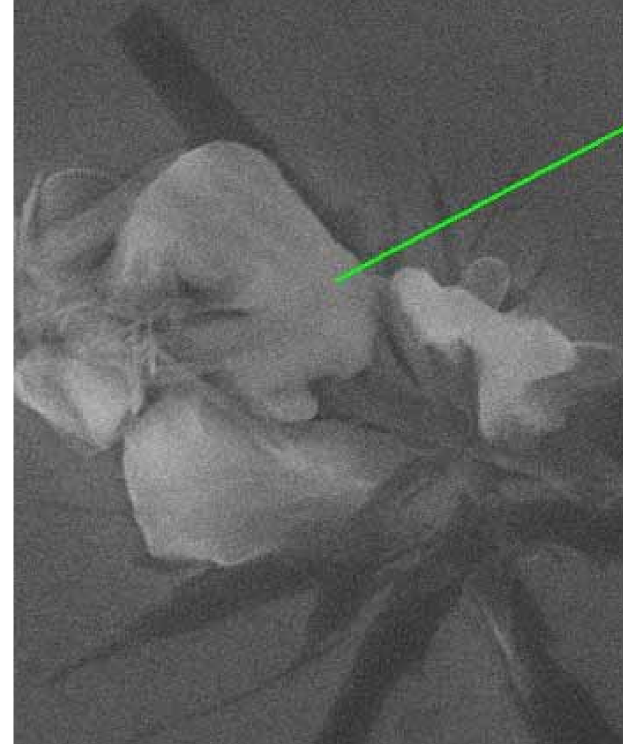
Surface inclusion (mainly iron) found in the sample extracted from one of XFEL prototype cavity

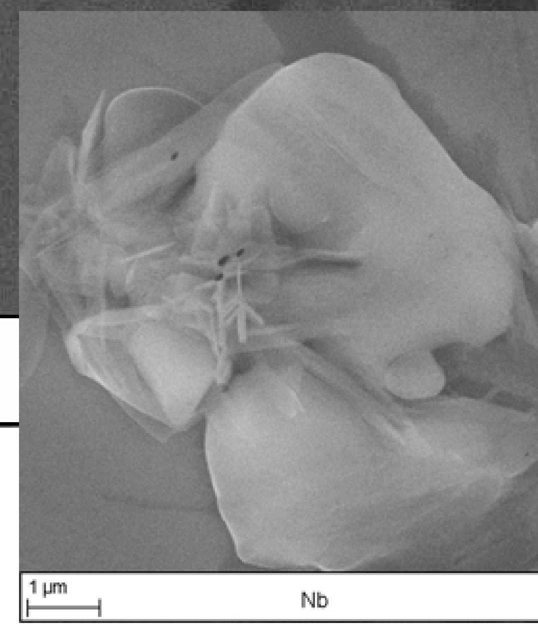



**(sodium) come from?**

**Beads of sweet of the hard working employees??**

**Tears from eyes as seen so many inclusions in the cavity??**



# Quality Assurance – Main Strategy

- The Manufacturer has to create and maintain a Quality Management System according EN ISO 9000 and
- According to requested by Orderer quality checks incl. documentation
  - The most of these checks are to be done by the contractor anyway but documentation must be transferred to Orderer "just in time" (QA action)
  - Special attention
    - Cell area of the Cavity
    - Welding connections

# Quality Assurance – Manufacturers Qualification

- The manufacturer and all its subcontractors have to demonstrate with their certification according ISO 9001:

  the ability consistently provide product that meets Orderer requirements and applicable statutory and regulatory requirements, and

  – aims to enhance Orderer satisfaction through the continual improvement of the system and the assurance of conformity to customer requirements and applicable statutory and regulatory requirements.

# Quality Assurance – Documentation

**The fixing of the Nomenclature of all existing objects will be the basis for a structured documentation**

- The Nomenclature is to be used for the whole contract by Manufacturer and Orderer
- Abbreviations are to be used to generate serial numbers.

**Examples:**

- ❑ Serializing of Nb-sheets
  - The serial number is made up of
    - “code letter” of Nb supplier
    - individual 5-digit number
  - Example: P00001 (Nb-sheet number one from Fa. Plansee)

- ❑ Serializing of dumb-bells
  - The serial number of a dumb-bell is made up of

- the abbreviation for dumb-bell (DB),
- an underscore „_“ and the SN of both used half-cells,

- Example: DB_H00123_H32100

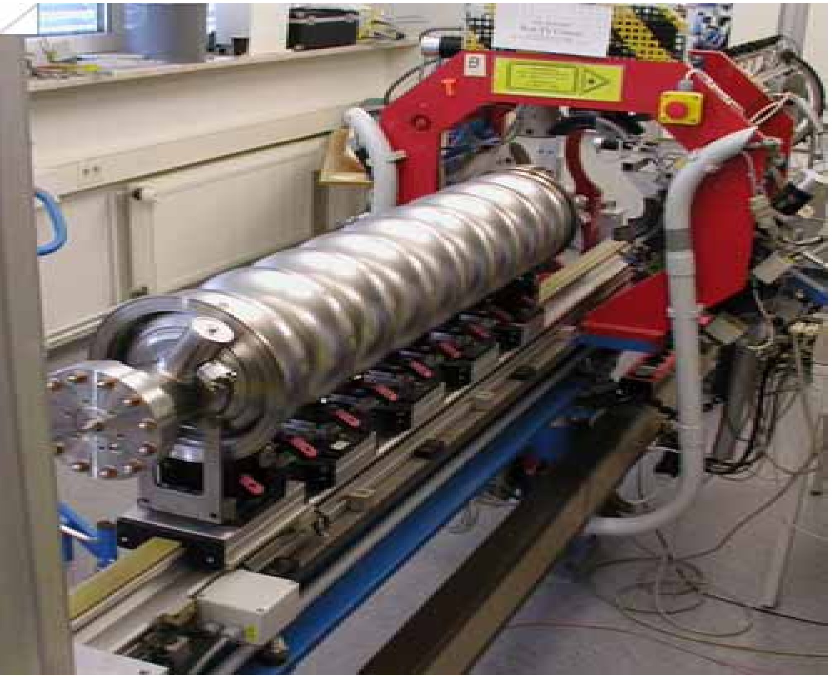
# Traceability

- For each completed cavity, a traceability report is to be prepared, in which the serial numbers of all incorporated semi-finished products and manufacturing groups are stated in the form of a parts list, including position information.
- It must be possible to reconstruct the development history of all products
- A conclusion concerning the raw material used should be possible.

# Quality Assurance – QC lists

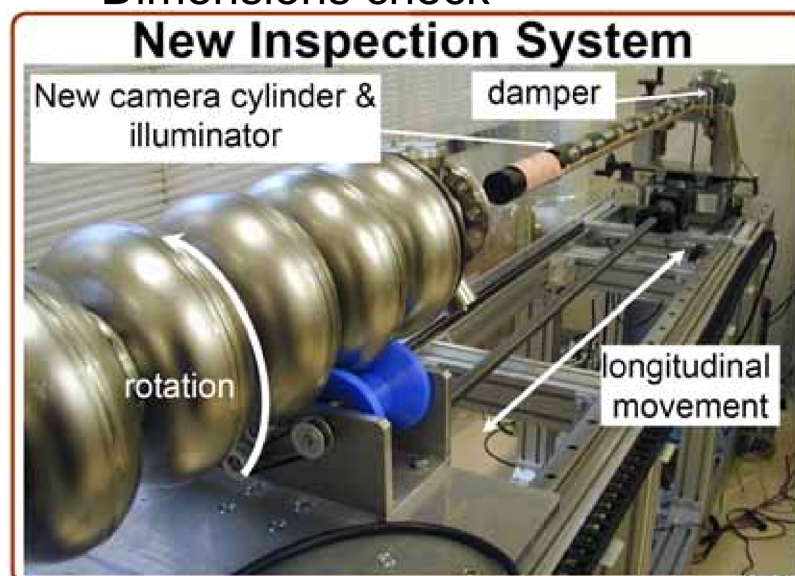
- Overview list
  – Lists all documents (certificates, test reports, …) with information of
    - Prescribed or recommended
    - hand over information
    - Storage information
- Detailed inspection list
  – Lists detailed the contents of the inspection sheets
- Orderer Inspection sheets
  – data of inspection sheets should be transferred to Orderer data base using Ordered templates

## Orderer inspection sheets



Eccentricity measurement

Dimensions check




Optical control of the inside surface

# Quality Assurance – special document

- Conformity Report (Confirmation of Conformity)
  - The manufacturer will prepare a conformity certificate for each completed cavity
  - It confirms that the cavity has been produced according to specification, and that all requirements have been checked and complied with the orderer.
  - Deviations are to be mentioned.

# Fabrication R&D Large grain LG

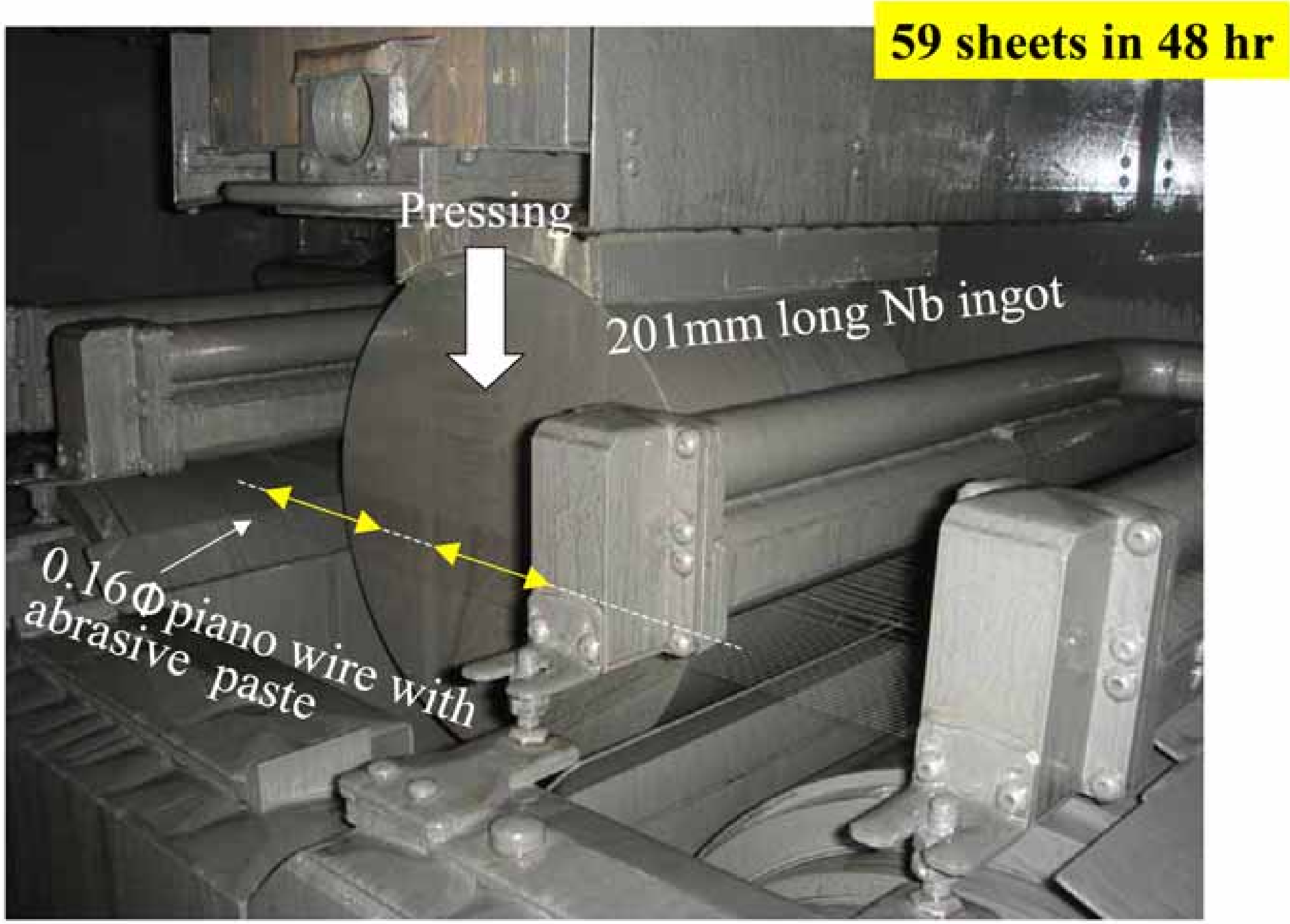

## Possible advantages (hope):

- Cost effective
- Higher purity. RRR=600 of ingot is achievable
- No danger that during many steps from ingot to sheet the material will be polluted.
- Simplified quality control (reduced number of measurements: grain size, eddy current scanning etc.)
- Higher thermal conductivity at low temperatures (phonon peak)
- Seems to be less susceptible to field emission (Univ. Wuppertal)
- Seems that the baking at 120°C works better after BCP (compare to fine grain BCP)

# Discs Slicing:

1. Before all else the multi- slicing of discs was developed at W.C. HERAEUS using diamond saw (B.Spaniol, LINAC 2006, TUP024)

2. **Successfully Multi-sliced 59 sheets (3.2t) from 201 mm long Nb Ingot**




Japanese Industry (more details in presentation of K.Saito, SRF2009)

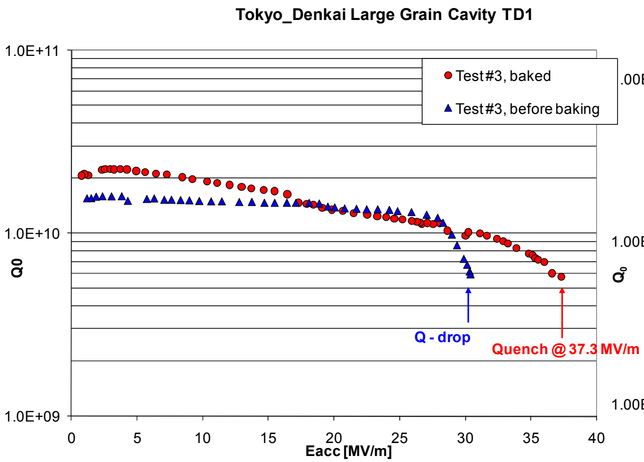
# Multi cell fabrication: For example 11 LG 9-cell cavities at RI from HERAEUS material fabricated DESY (**AC112-AC114, AC151-AC158**)

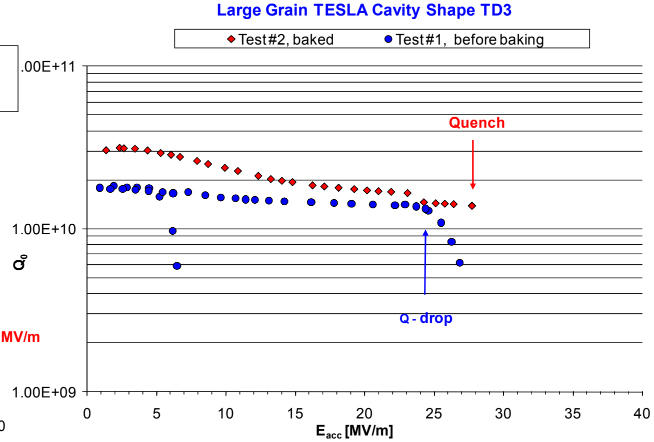
**Fabrication:**

- **Discs scanned only for two cavities.**
- **Deep drawing**
- **Machining**
- **EB welding**
- **Grinding of grain boundaries on 4 cavities for comparison**

In discs for AC151-AC154, the main orientation of the central crystal is (100), for discs of AC155-AC158 mainly (211) or (221). For the disc with (100) orientation, a more pronounced anisotropy and quadrangular shape after deep drawing was observed. The difficulties for assembling of half cells and dumb-bells for welding have been overcome by using a special tool

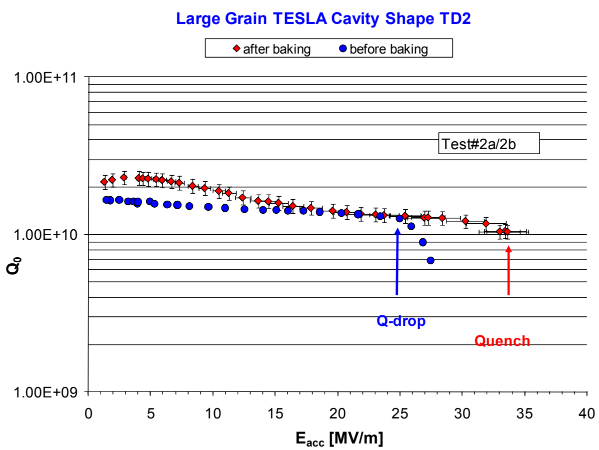
# Reasonable performance and reproducibility have been demonstrated on single cell LG cavities with BCP by JLAB, DESY, and KEK/IHEP

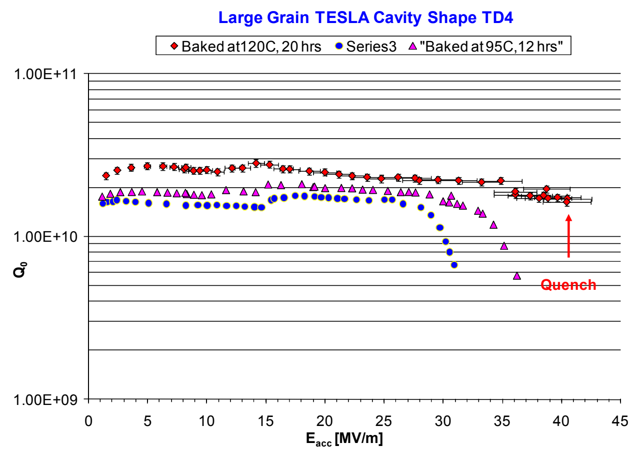


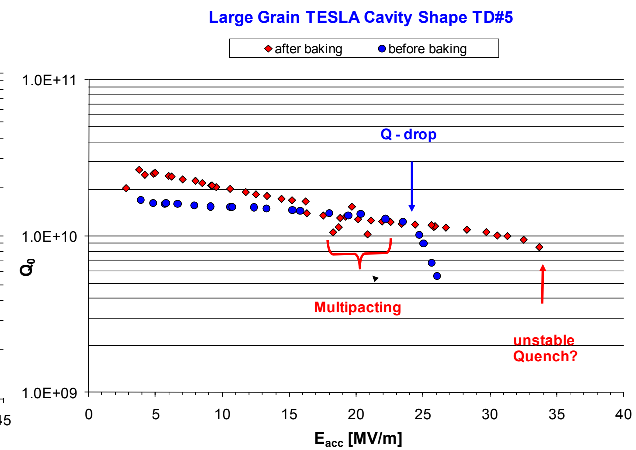




All cavities treated:

- 100 micron bcp (1:1:1)
- 600 C, 10 hrs
- 30 micron bcp, HPR
- RF-Test
- If no FE, baking at 120C for 20 hrs
- Re-testing



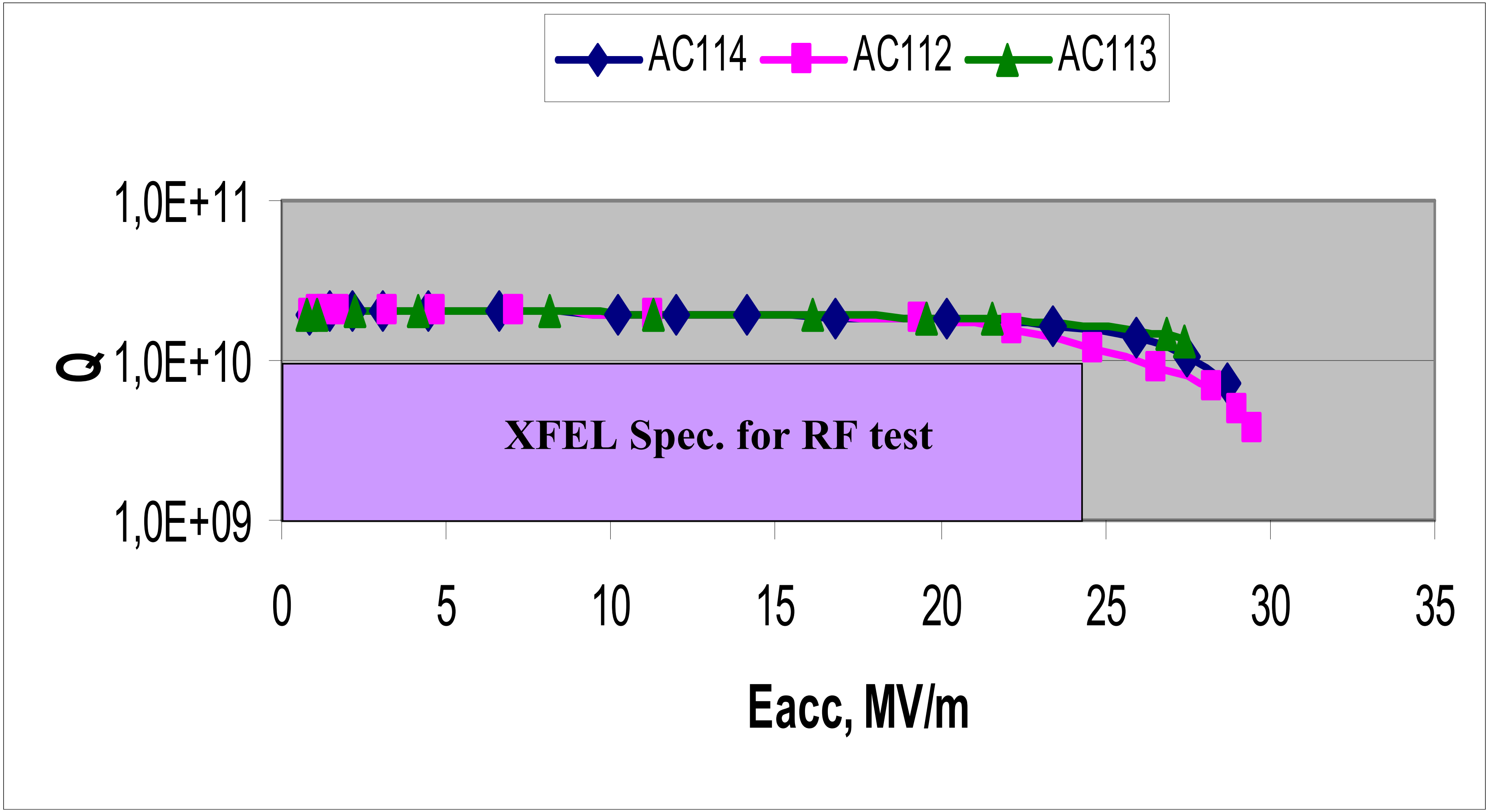



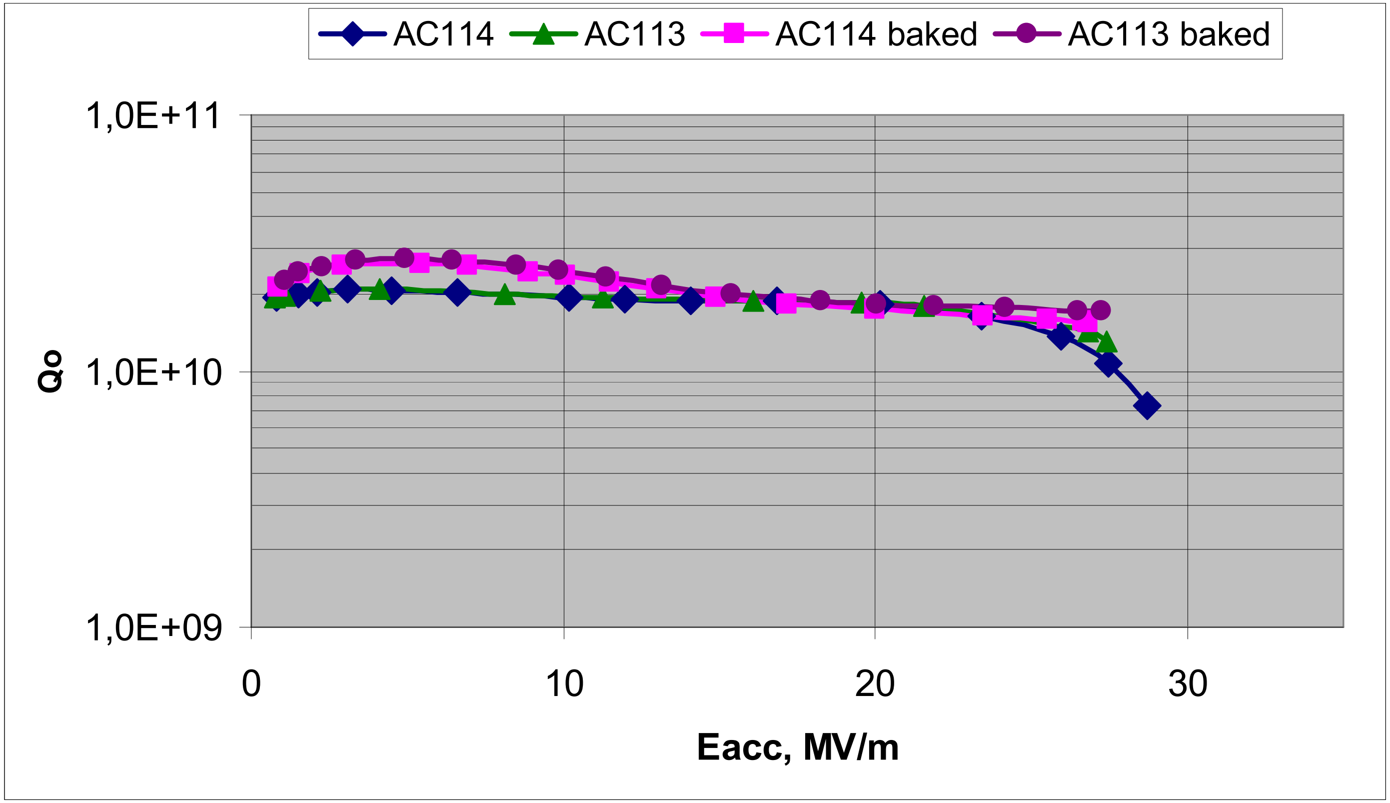




Reproducibility Tests of LG Niobium Cavities (P. Kneisel, JLab)

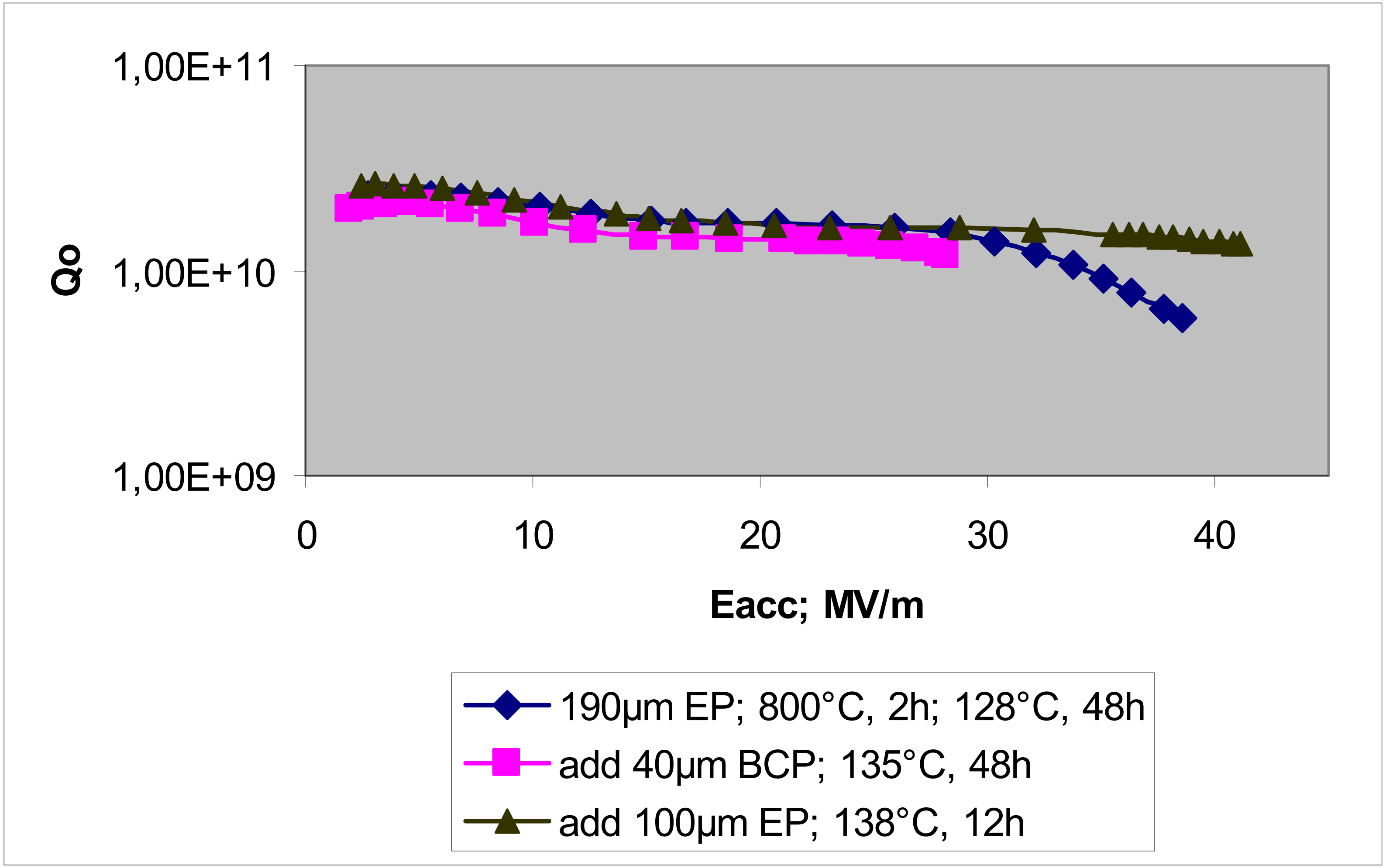
Encouraging results on multi cell LG cavities after BCP:

Q(Eacc) curve of the LG nine cell cavities AC112- AC114 at 2K after 100 µm BCP, 800°C, 20 µm BCP, HPR



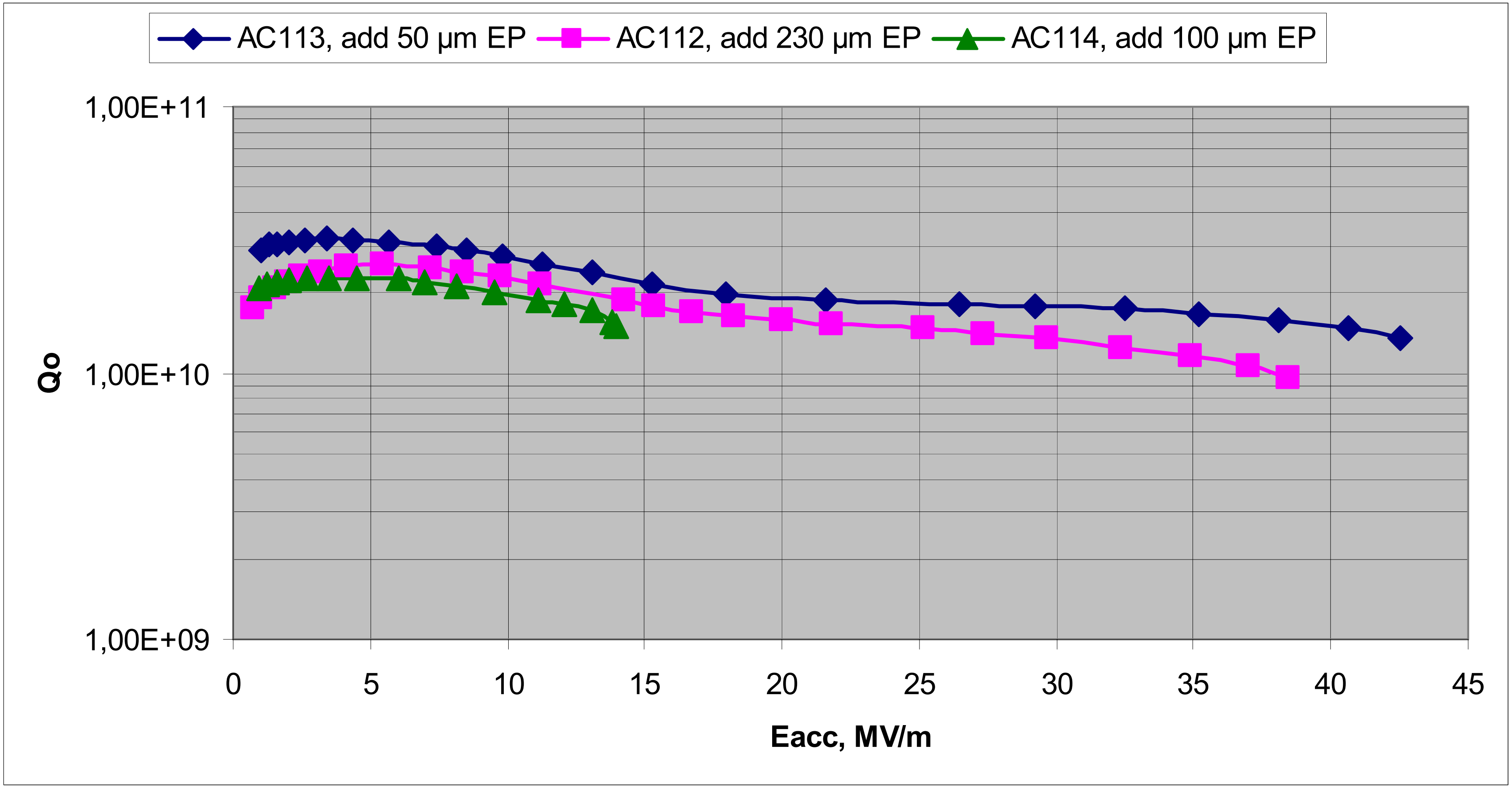



Second test Q(Eacc) curve of the LG nine cell cavities AC113-AC114 at 2K after additional 20-30 µm BCP and 125°C, 50 h baking




It seems that EP works better

Q(Eacc) curve of the single cell cavity 1AC4
after EP and BCP treatment




## EP on 3 DESY LG Cavities:

Additional EP of 50-100 µm, combined with additional "in situ" baking. Enhancing the acceleration gradient by approx. 10 MV/m can be seen on two cavities (AC112 and AC113). Surprisingly, significant degradation of Eacc from 28 to 14 MV/m for the cavity AC114

# Multi cell LG activities: Several Labs are working on LG multi cell cavities

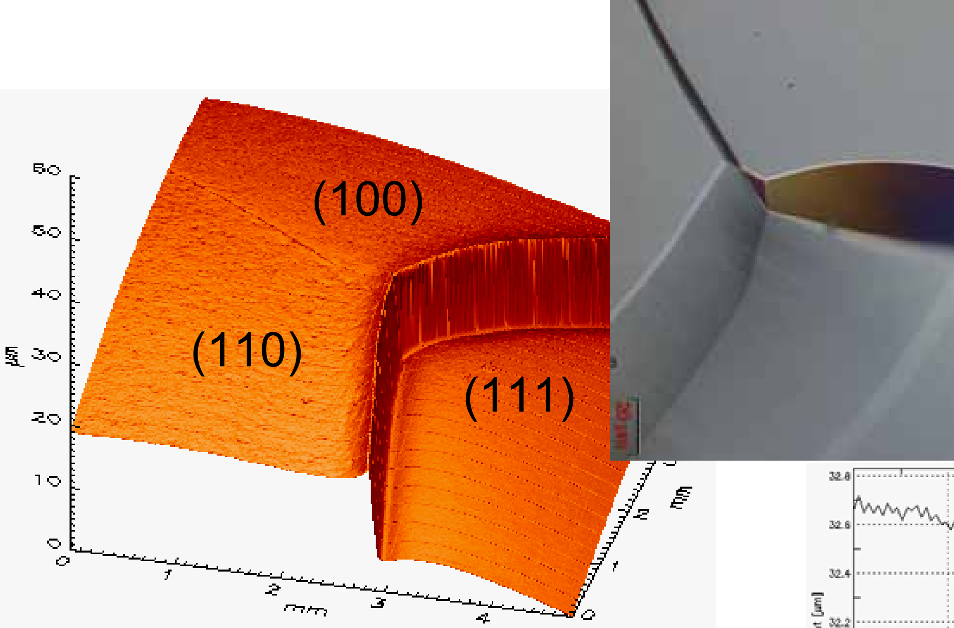
JLab: Two Jlab upgrade 7-cell cavities are completed from Ningxia/ CBMM large grain Nb

Jlab:Two LL/Ichiro 9-cell ILC cavities are in fabrication from Tokyo-Denkai and CBMM material

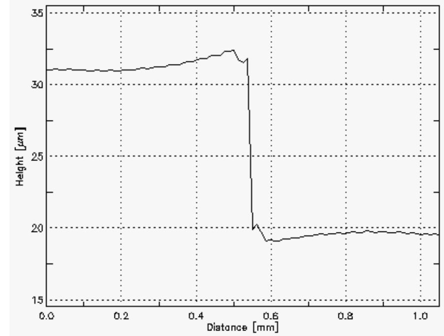
Pekin Univ: LG two cell cavity

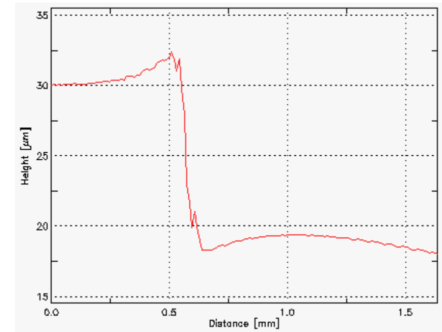
IHEP works on two 9-cell LG 1,3 GHz CVs

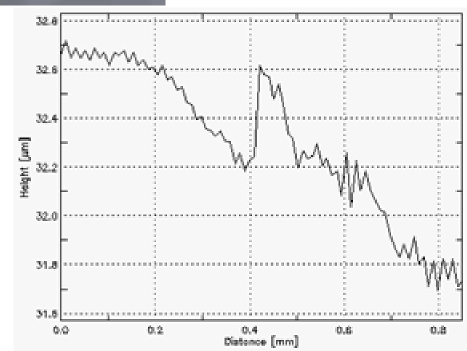
JLab: 2-Cell large Grain CRAB Cavities



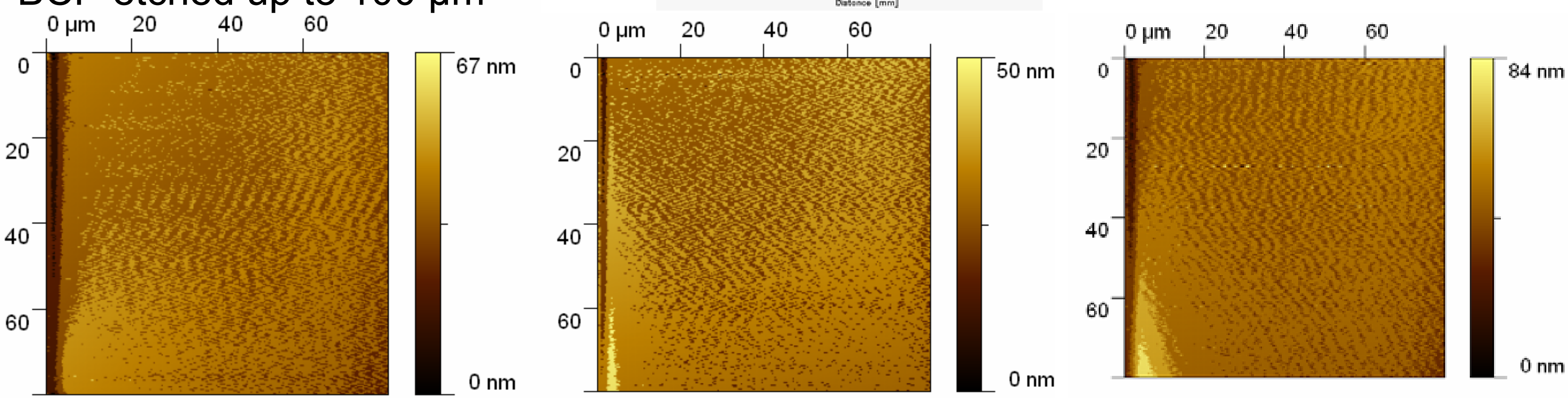

Light microscope and AFM image of LG Nb, BCP etched up to 100 µm




Profile and step heights of the three grain sample at the grain boundary intersection




AFM roughness measurement (X. Singer, A. Dangwal-Pandey). Roughness of fine grain Nb after EP is 251 nm (A. Wu) .

# Single Crystal Option

## Better not to have the grain boundaries at all

Fabrication of TESLA shape single crystal single cell cavities was proposed at DESY.

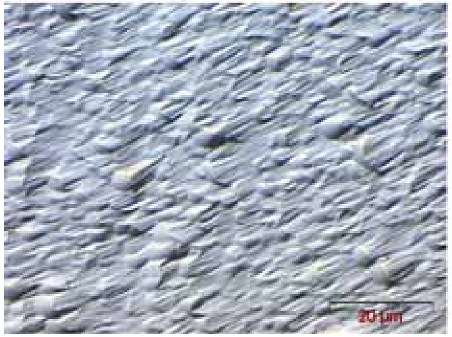
Following aspects have been investigated and taken into consideration during cavity fabrication

• Definite enlargement of the discs diameter is possible without destroying the single crystal structure in an existing state.

• Appropriate heat treatment will not destroy the deformed single crystal

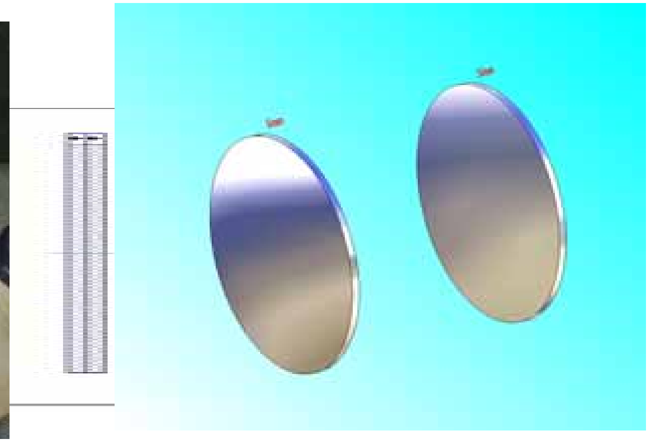
• The single crystals keep the crystallographic structure and the orientations after deep drawing and annealing at 800°C

• Two single crystals will grow together by EB welding, if the crystal orientations is taken into account.



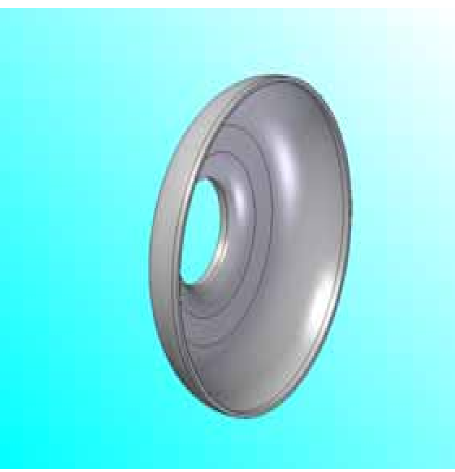
# Single crystal cavity fabrication (DESY- JLab)

1. Take out central single crystal of definite thickness

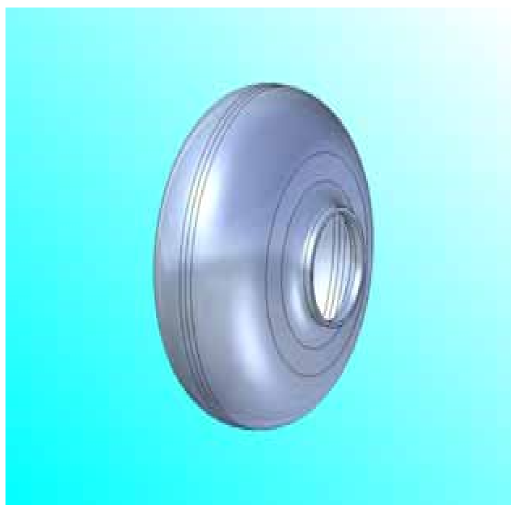


2. Cutting through the disc

3. Increasing of diameter by special rolling with an intermediate annealing



4. Deep drawing



5. EB welding by matching the crystal orientation

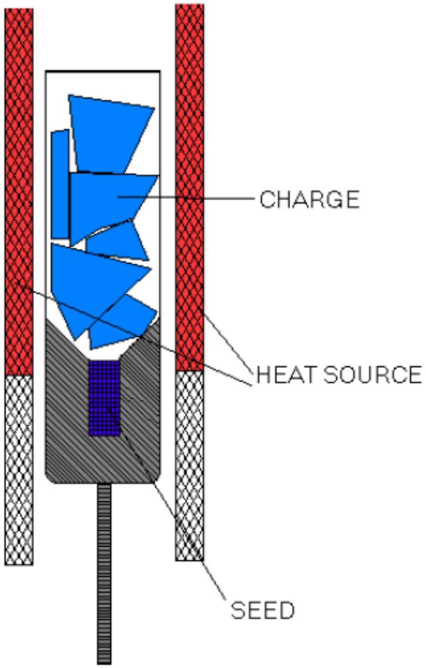
Single Crystal Cavities with three different crystal orientation

# One large grain (single crystal) is a promising option that allows stably reach very high gradient by simple BCP treatment

| Cavity # | $E_{acc,max}$ (MV/m) | $B_{peak,max}$ (mT) | $Q_0(B_{peak,max})$ | Treatment |
|---|---|---|---|---|
| 1 | 38 | 162 | $4\times10^{9}$ | 200µm BCP, 800°C 3h, HPR, 120°C 48h |
| 2 | 45 | 160 | $7\times10^{9}$ | 200µm BCP, 800°C 3h, HPR, 120°C 24h |
| 3 (1AC6) | 41 | 177 | $1.2\times10^{10}$ | 250µm BCP, 750°C 2h, 120µm EP, HPR, 135°C 12h |
| 4 (1AC8) | 38.9 | 168 | $1.8\times10^{10}$ | 216µm BCP, 600°C 10h, HPR, 120°C 12h |
| 5 | 38.5 | 166 | $7.6\times10^{9}$ | 170µm BCP, HPR, 120°C 12h |

W. Singer. Tutorial. 14th International Workshop on RF Superconductivity, September 20-25, 2009, Dresden, Germany

# Is it realistic produce single crystal cavities of sizes required for ILC?




Vertical Bridgman procedure for single crystal grow

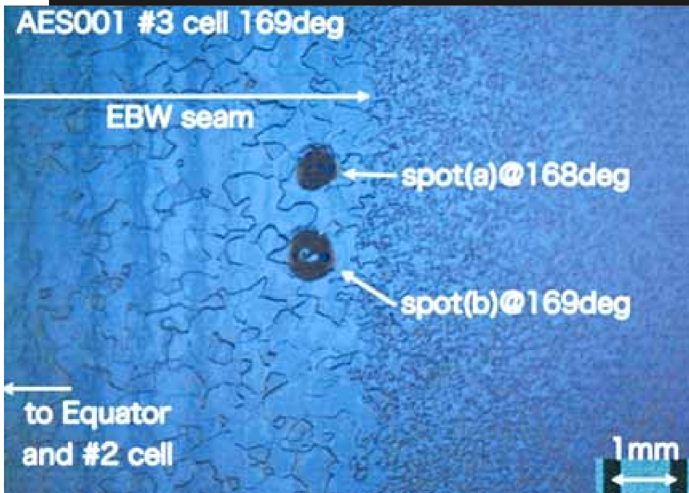
1. Seed, partially melted
2. Axial temperature gradient
3. Interface between solid and liquid phase is shifted by movement of container or temperature gradient

SC Ca. 200 mm

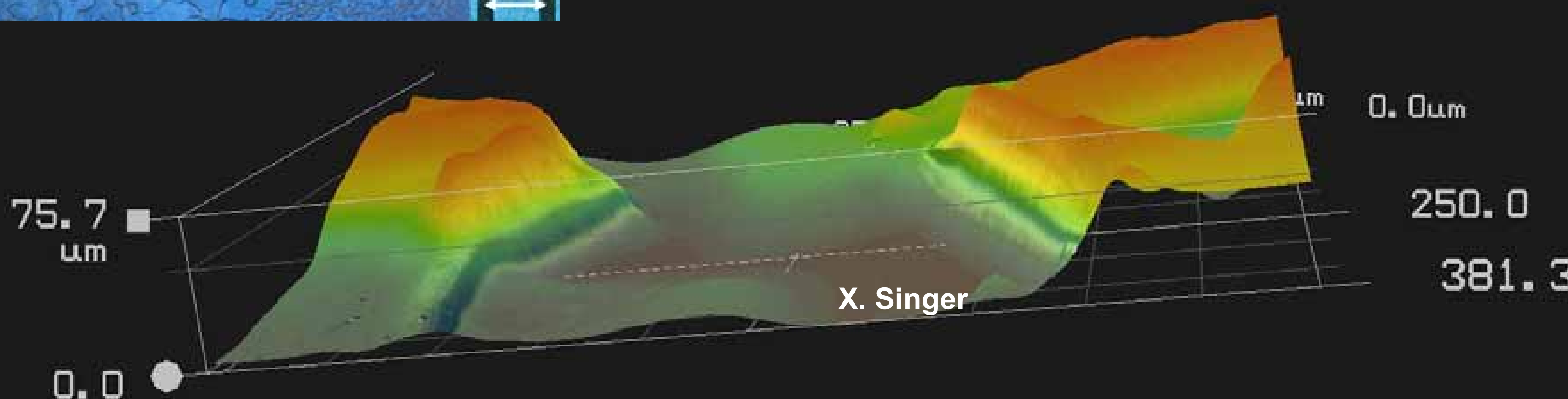
Electron beam melting principle

**Challenge for the industry**

# Fabrication R&D: Seamless fabrication



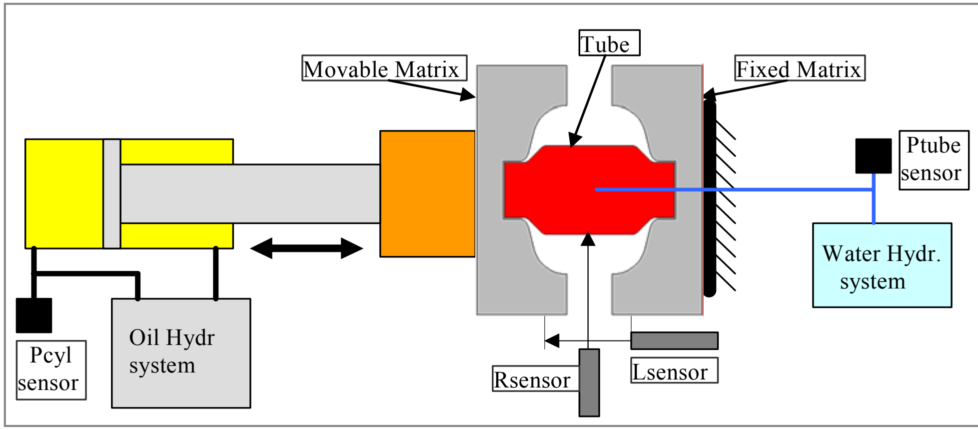

Welding seam is critical even without pits problematic




Example of welding connection of EP treated cavity. Up to 75 µm steps

# Fabrication R&D: Seamless fabrication

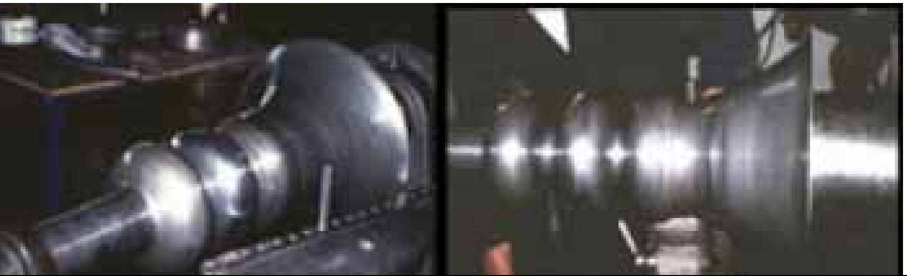
## Hydroforming, DESY, KEK, MSU





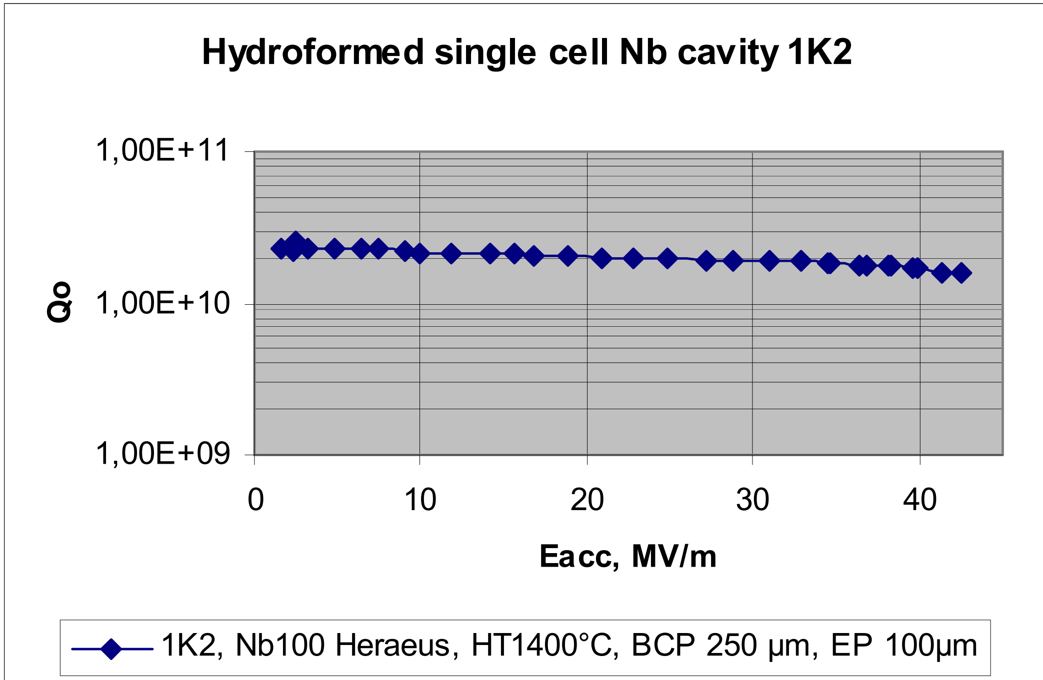
DESY hydroforming machine
HYDROFORMA

## Spinning (V.Palmieri, INFN Legnaro)



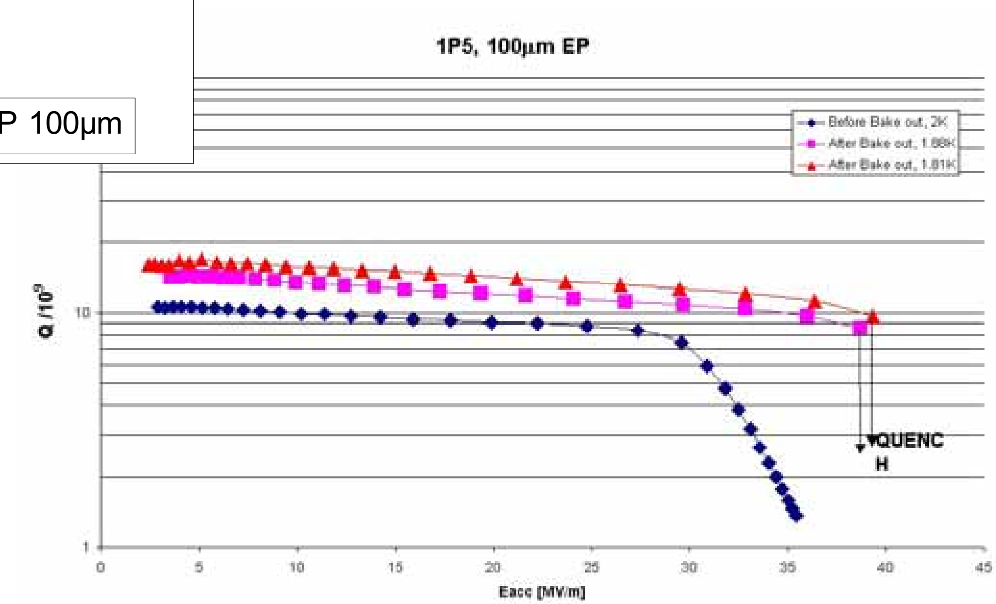
# Hydroforming, Spinning

## Proof of principle is done on single cell cavities




The best Q(Eacc) result of by hydroforming produced single cell cavity

The best Q(Eacc) result of by spinning produced single cell cavity

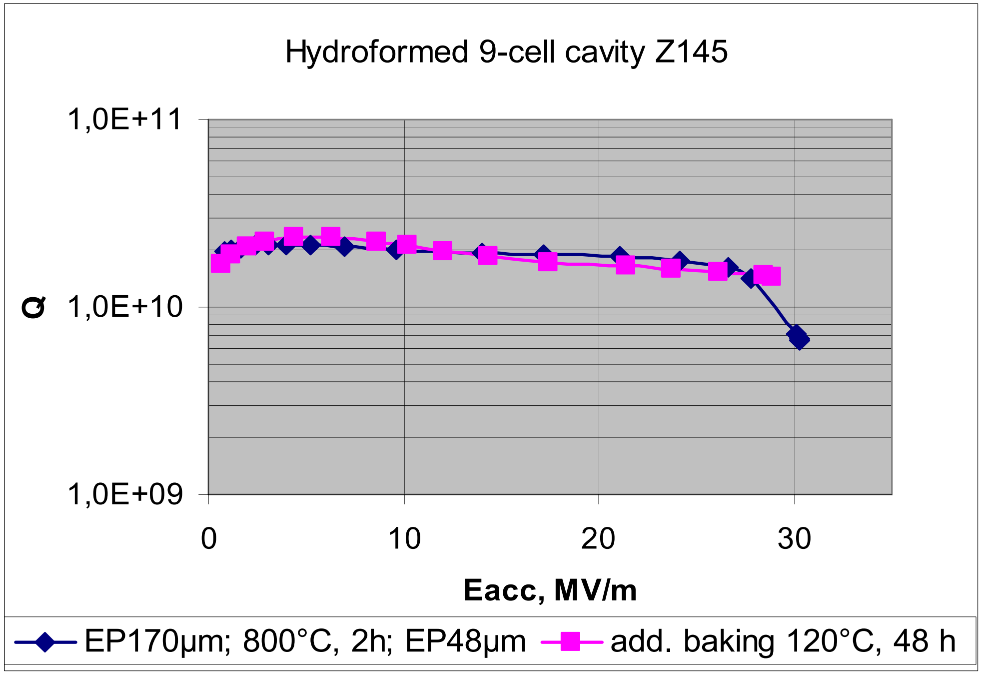


# Fabrication of 9 cell cavities became a reality

**INFN Spun cavity**

**DESY Hydroformed cavity completed from 3x3 cell units**

# DESY cavity Z145: 9-cell cavity RF test results




Surface treatment at DESY: 40 mm BCP, 800 °C heat treatment, tuning; 170 mm electropolishing (EP), ethanol rinsing, 800 °C heat treatment; 48 mm EP, HPR, assembly and evacuation. After "in-situ" baking at 120 °C for 48 h. the Q-drop almost disappeared, but the Eacc was not increased. The cavity is welded into the He vessel, will be installed in one of next acc. cryomodules at DESY.

**Mode limits of cavity Z145 measured on 23-Jul-2008 13:08**

| | Pi | 8/9 Pi | 7/9 Pi | 6/9 Pi | 5/9 Pi | 4/9 Pi | 3/9 Pi | 2/9 Pi | 1/9 Pi | Max Field | Limit. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cell 1&9** | *30.29* | *27.34* | *29.67* | *28.39* | *26.26* | *25.39* | *17.62* | *8.21* | *5.95* | ***30.29*** | ***bd*** |
| **Cell 2&8** | *30.29* | *24.05* | *15.79* | *.00* | *17.14* | *34.21* | *35.24* | *20.79* | *17.15* | ***35.24*** | ***bd*** |
| **Cell 3&7** | *30.29* | *17.85* | *5.48* | *28.39* | *32.21* | *13.51* | *17.62* | *23.64* | *26.27* | ***32.21*** | ***pwr*** |
| **Cell 4&6** | *30.29* | *9.50* | *24.19* | *28.39* | *5.95* | *38.91* | *17.62* | *15.43* | *32.22* | ***38.91*** | ***pwr*** |
| **Cell 5** | *30.29* | *.00* | *31.57* | *.00* | *34.28* | *.00* | *35.24* | *.00* | *34.29* | ***35.24*** | ***bd*** |
| **Limit** | ***bd*** | ***bd*** | ***bd*** | ***bd*** | ***pwr*** | ***pwr*** | ***bd*** | ***pwr*** | ***bd*** | | |

# DESY, KEK, FNAL, MSU, Black laboratories et al continue, or started, or planning to start seamless activities

New DESY multi cell units produced by hydroforming

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