RRR Degradation and Gas Absorption in the EB Welding Seam of High Purity Niobium

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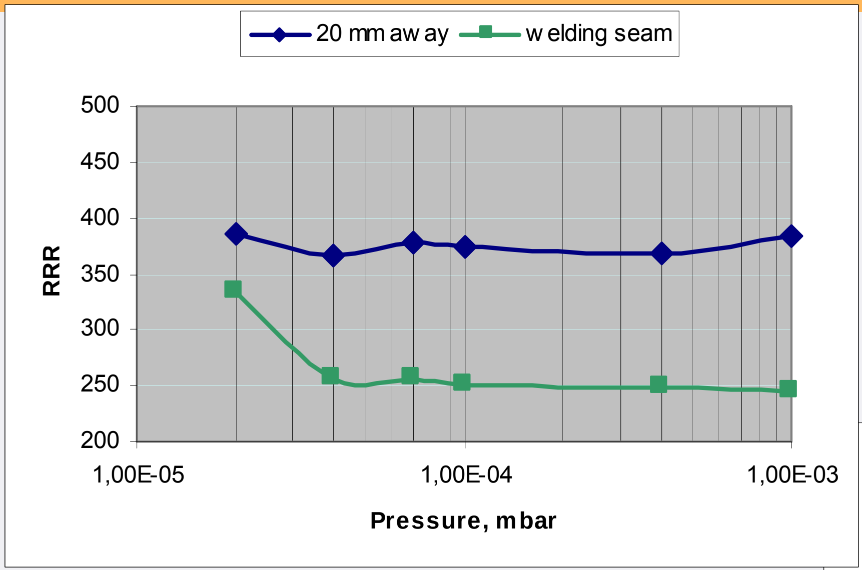
- **Purity degradation/improvement of Nb during EB welding?**
- **Hole burned through by electron beam**

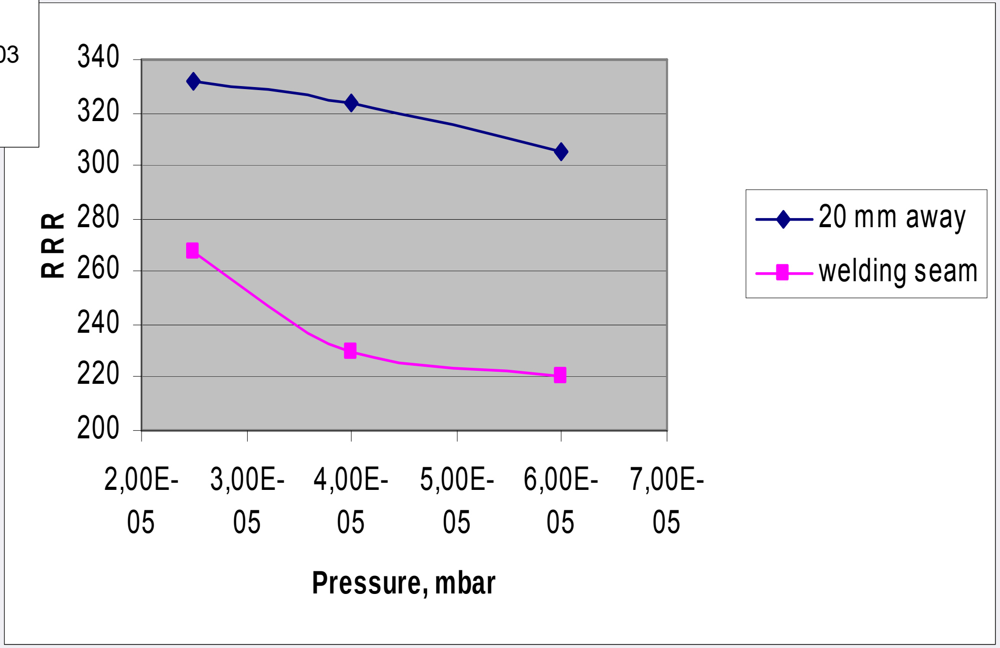
EB welding of Nb at different companies



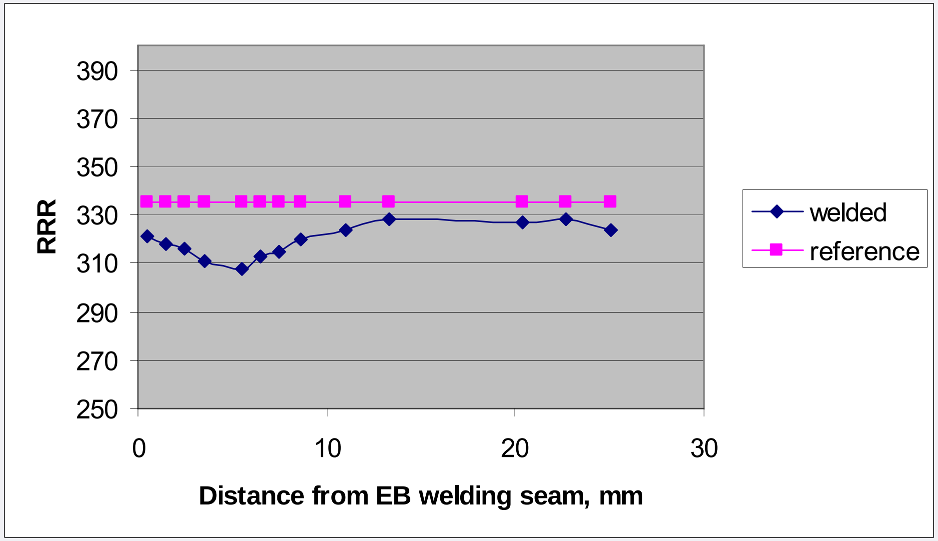
RRR degradation of Nb in the EB welding seam takes place for pressure 10^{-3} - 10^{-5} mbar

RRR in the welding seam and 20 mm away versus pressure in the chamber during EB welding (Fa. Dornier 94)

RRR in the welding seam and 20 mm away versus pressure in the chamber during EB welding (Fa. Zanon 95)



EB welding of Nb at different companies



FNAL SRF2003 (EBW Sciaky company, pressure 4x10-5 mbar)

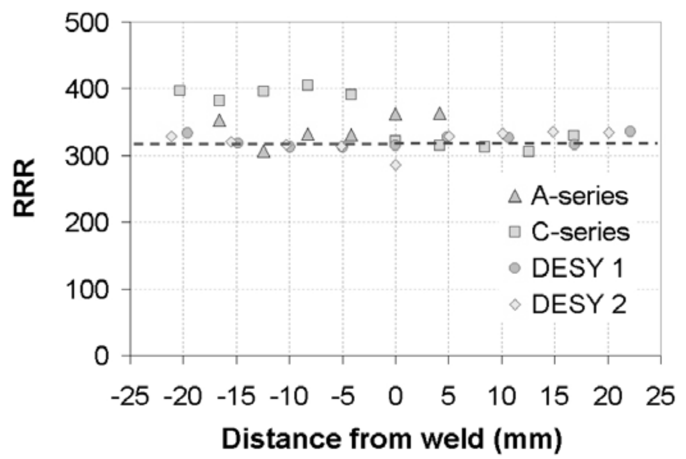
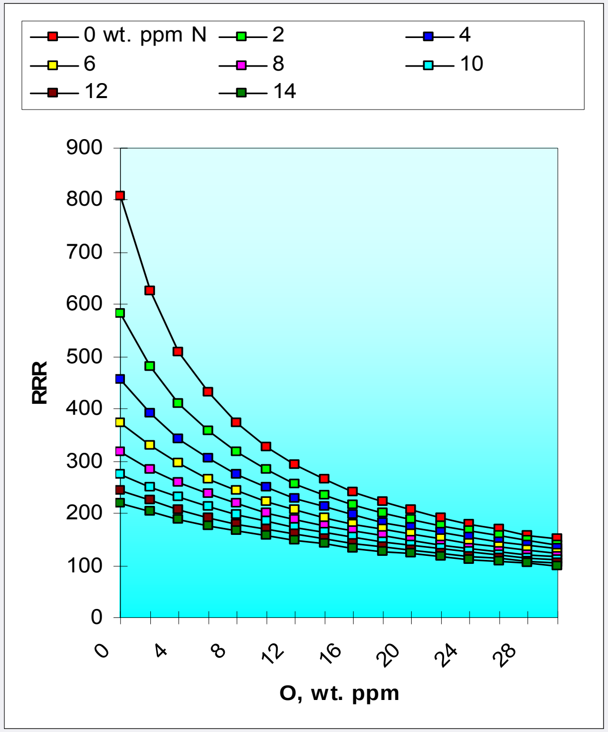


Figure 4: Weld-series RRR for CKM Nb vs. distance from weld. The dashed line indicates the RRR before welding. A&C/DESY1&2 were measured at FNAL/DESY.

RRR in the EB welding area versus distance from the welding seam (welded at pressure 2x10-5 mbar, ACCEL 96)

RRR degradation takes place at the welding seam as well as at the thermally affected area and depends on the company

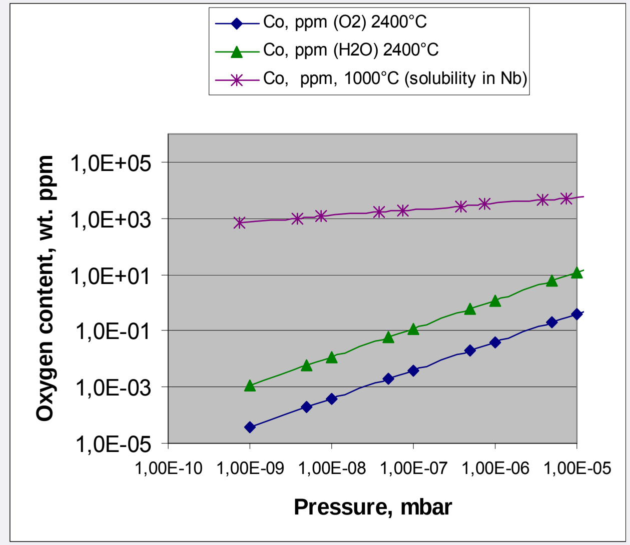
RRR dependence on oxygen and nitrogen content (calc.)



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

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

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

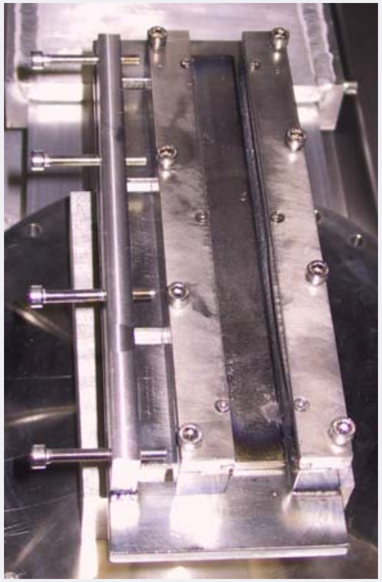
Kinetic of process is of grate importance

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

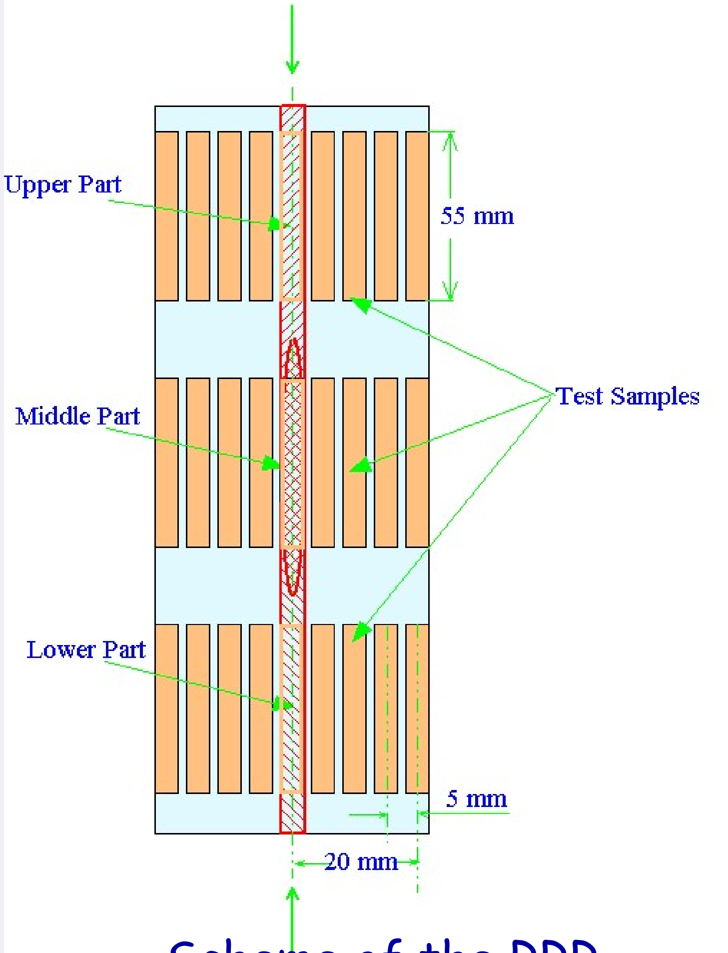
For concentration change ΔC of 4 wt. ppm, sample thickness d=2 mm, equilibrium pressure p=10^{-6} mbar the degassing time is t=800 sec.

Welding in DESY EB Equipment

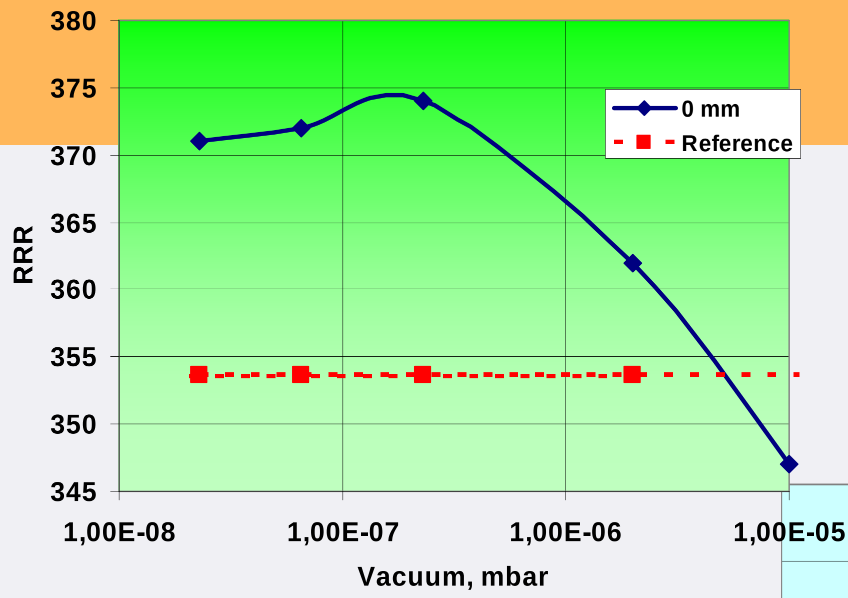
- Pressure range of EB welding was 10^{-5} -10^{-8} mbar, thickness at welding area 1,8 mm, welding speed ca. 8 mm/sec
- Welding procedure: tack, 50% penetration (circle raster), full penetration (circle raster)
- During welding the total pressure reaches the order of magnitude 10^{-6} mbar (independently of the initial pressure)



Clamping system for EB welding and example of Nb welding strip

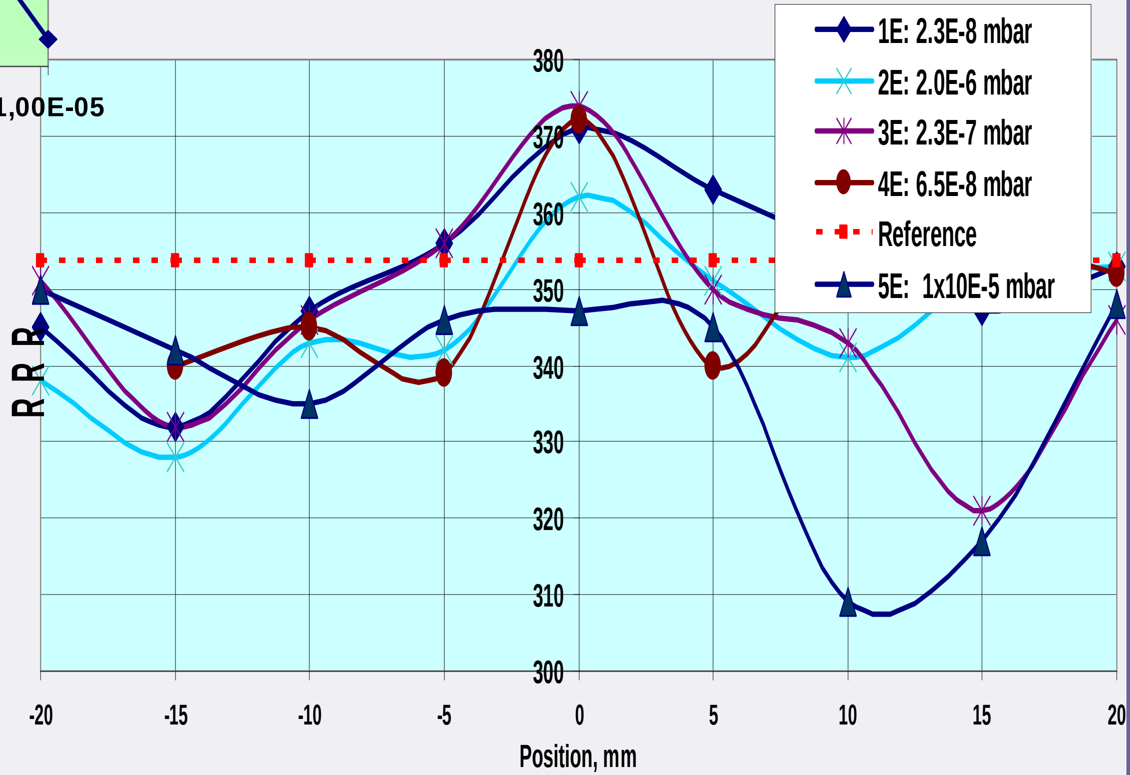


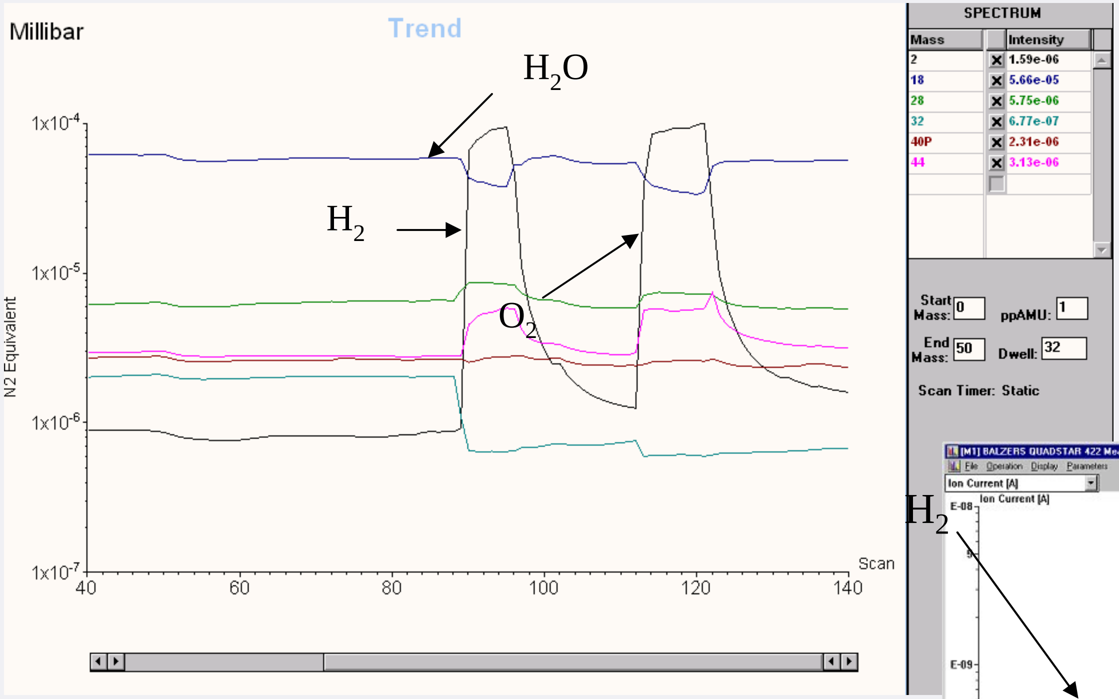
Scheme of the RRR samples cut off



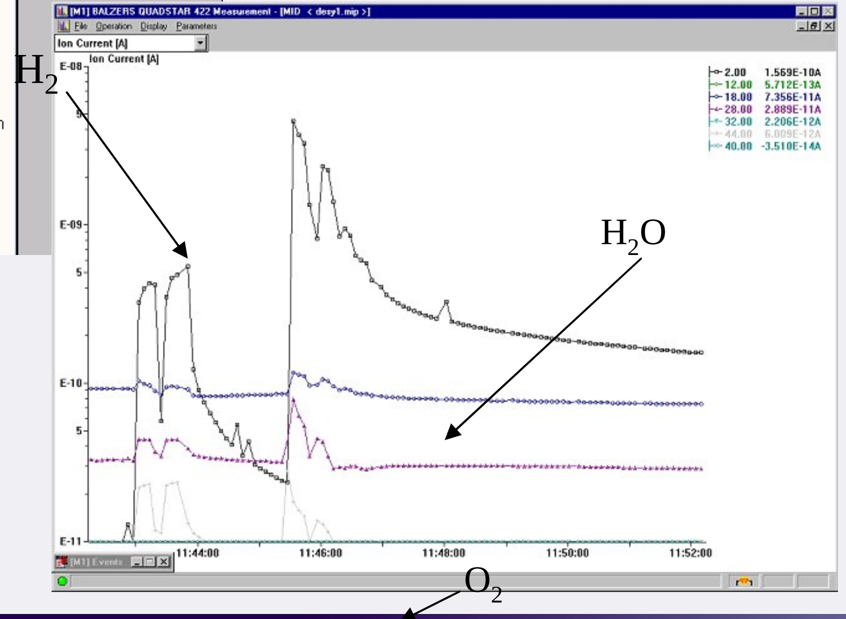
The RRR degradation at welding seam started since pressure of ca. 10-5 mbar

The RRR degradation take place in the area close to welding seam (thermally affected area)

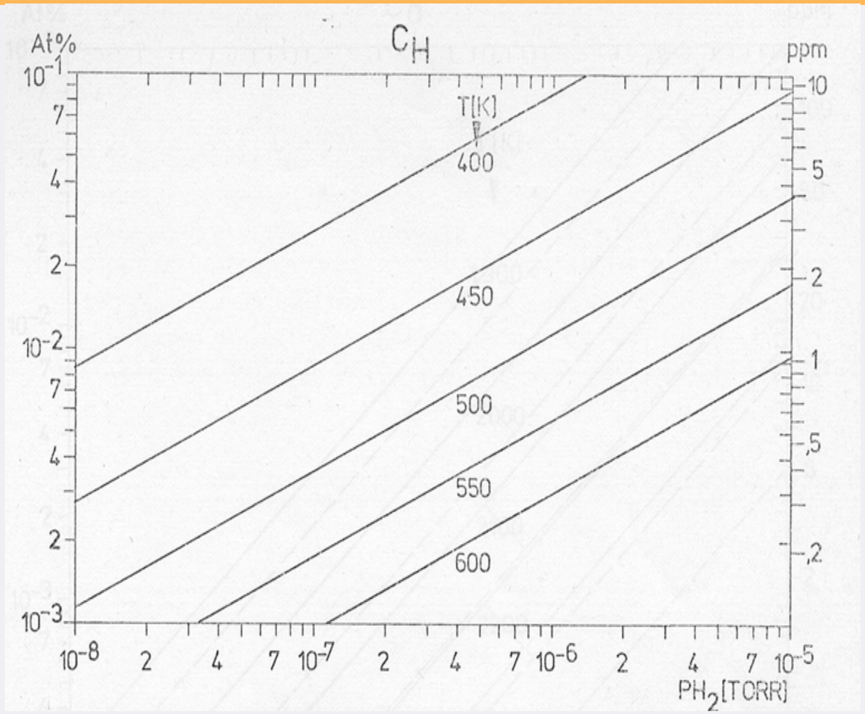




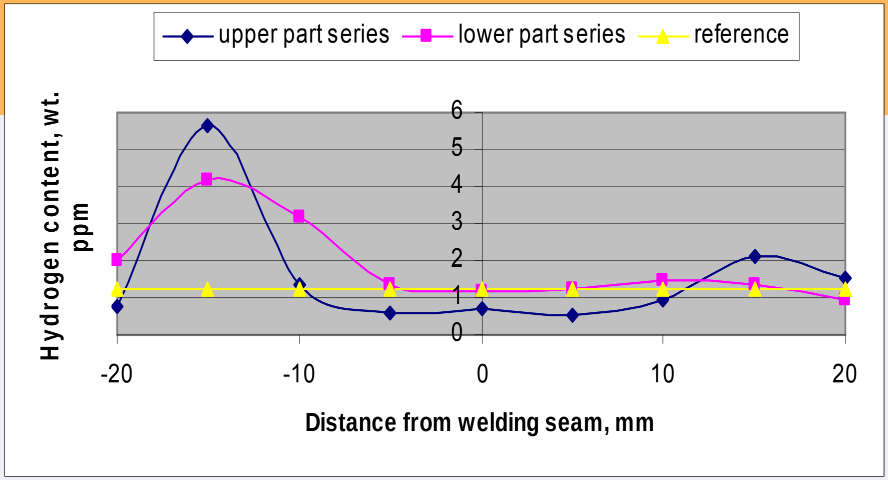
Partial pressure in the EB chamber (CERCA) during welding of Nb300sample (on the left)

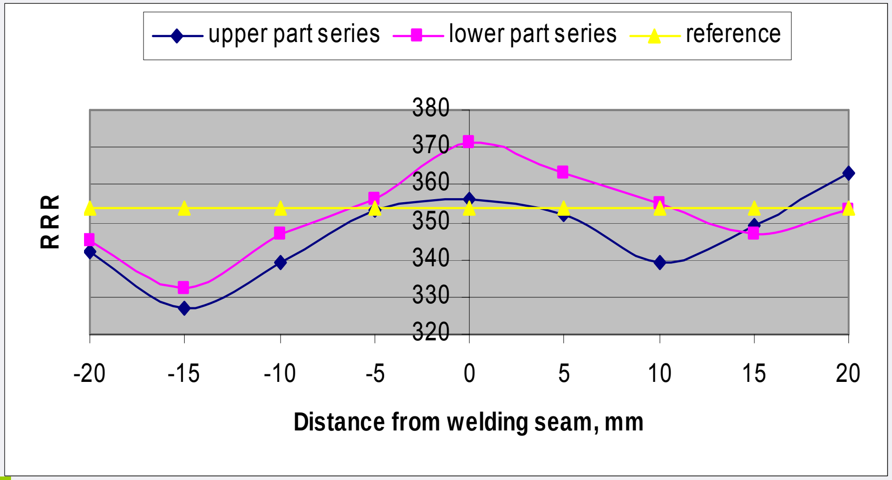


Partial pressure in the EB chamber (DESY: 6,5x10^{-8} mbar) during welding of Nb300 sample (on the right)



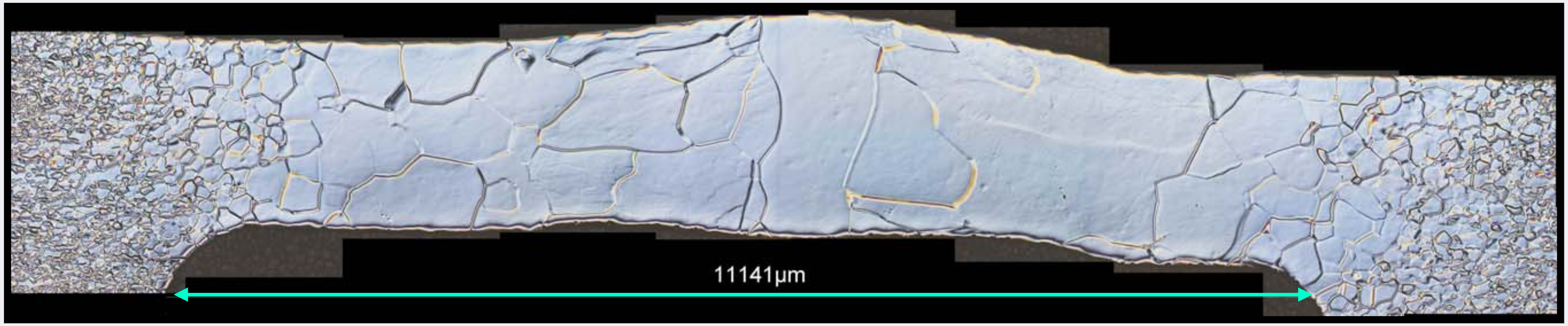
Pressure – concentration isotherms of hydrogen in Nb in steady state condition





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

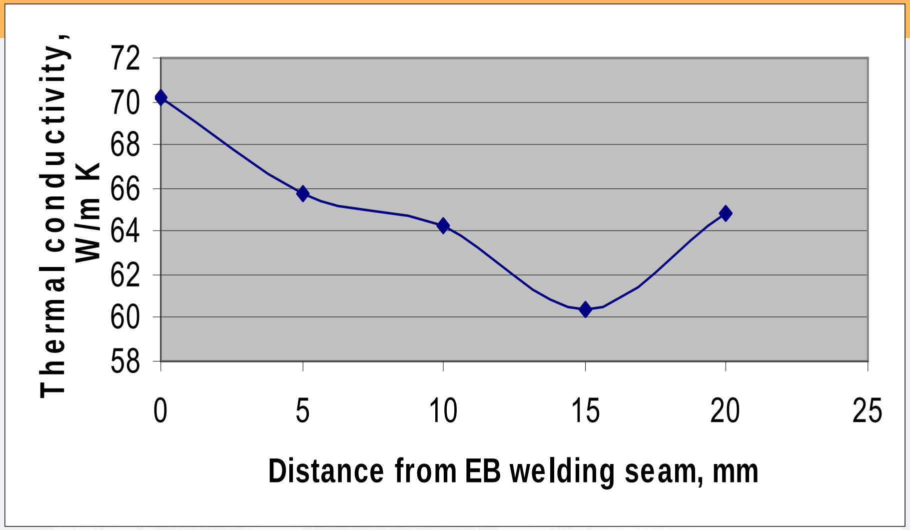
Comparison of RRR and hydrogen content in welding area (pressure $2.3x10^{-8}$ mbar)



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

Thermal conductivity of Nb in the superconducting state (parametrisation done by F. Koechlin and B. Bonin)

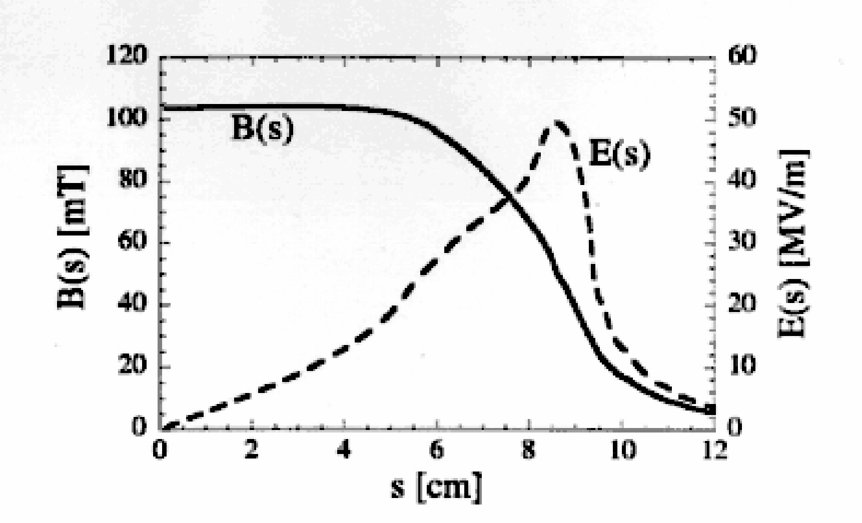
$$\lambda(T, RRR, G) = R(y) \cdot \left[\frac{\rho_{295K}}{L \cdot RRR \cdot T} + a \cdot T^2 \right]^{-1} + \left[\frac{1}{D \cdot \exp(y) \cdot T^2} + \frac{1}{B \cdot G \cdot T^3} \right]^{-1}$$



Example of thermal conductivity behavior in EB welding area calculated at 4,2K for samples welded at pressure 2,3x10-7 mbar

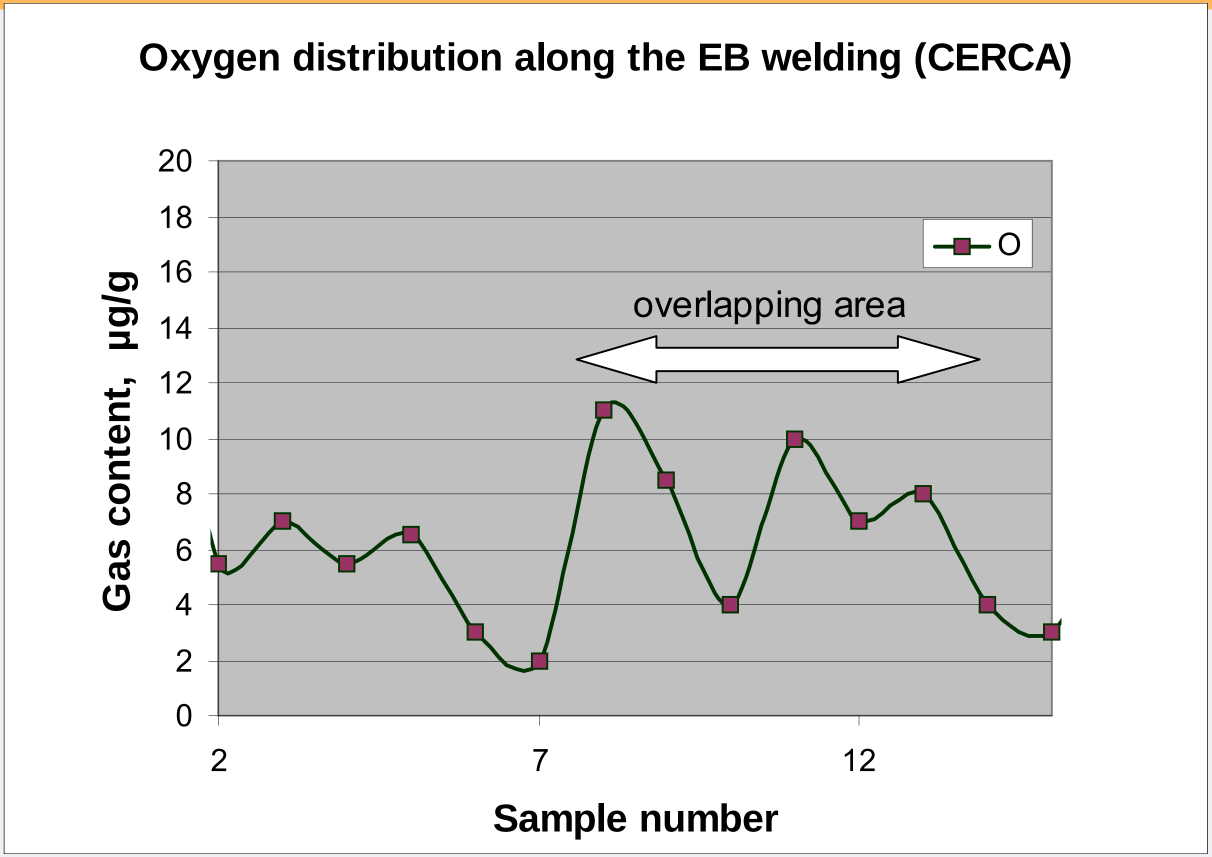
Thermal conductivity has a minimum not directly at the welding seam, but in thermally affected area.

Thermally affected area is more critical for break down as the welding seam itself.



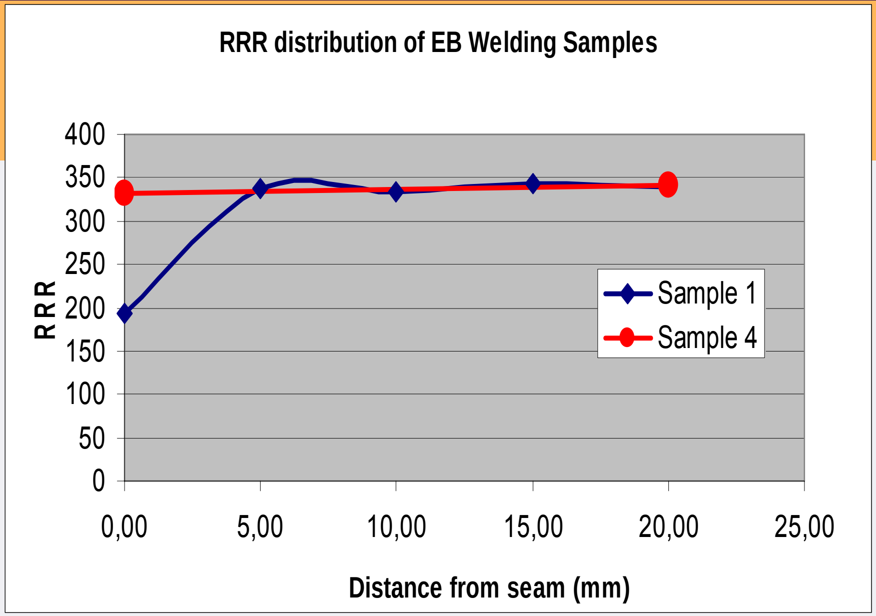
Distribution of the magnetic and electrical field from equator to the iris on the surface of the TESLA cavity

RRR degradation

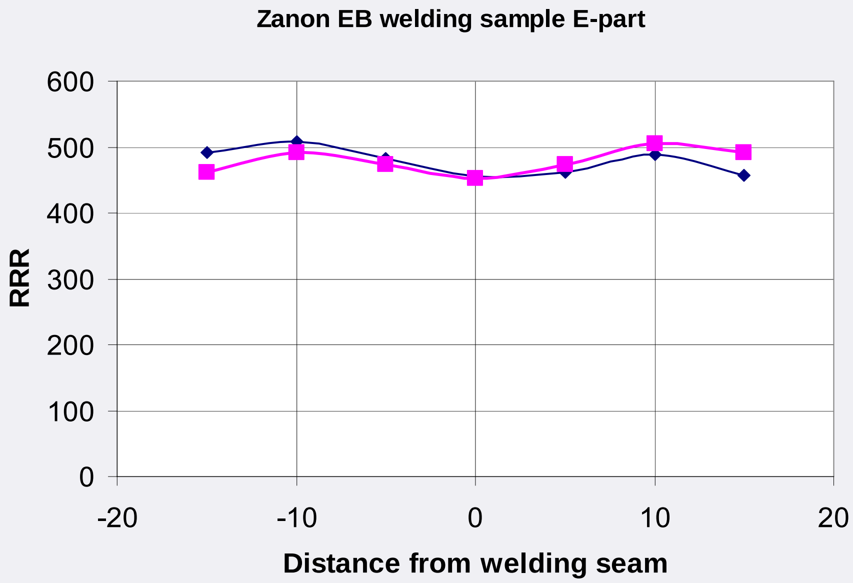


Oxygen distribution along the welding seam. RRR= 280 in the welding seam and RRR= 207 in the overlapping.

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



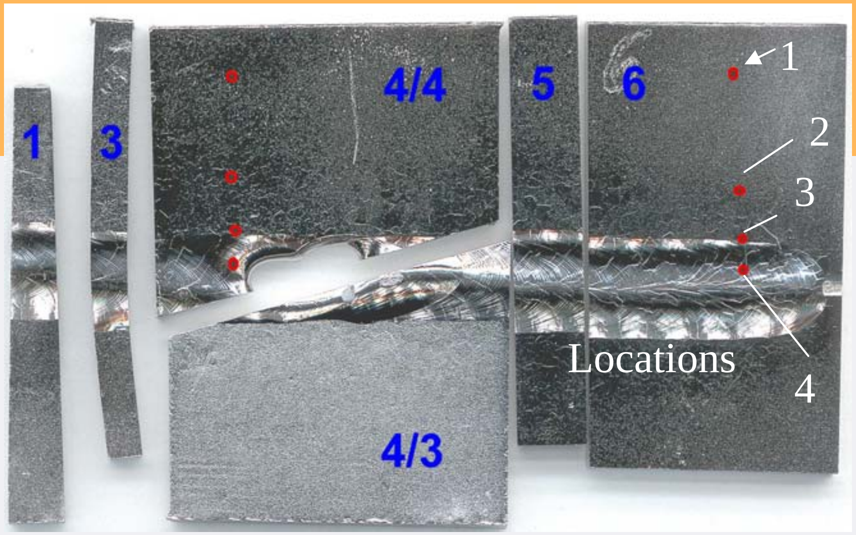
RRR in the welding seam area with (sample 4) and without (sample 1) of Nb evaporation in the EB chamber (DESY+Julich)



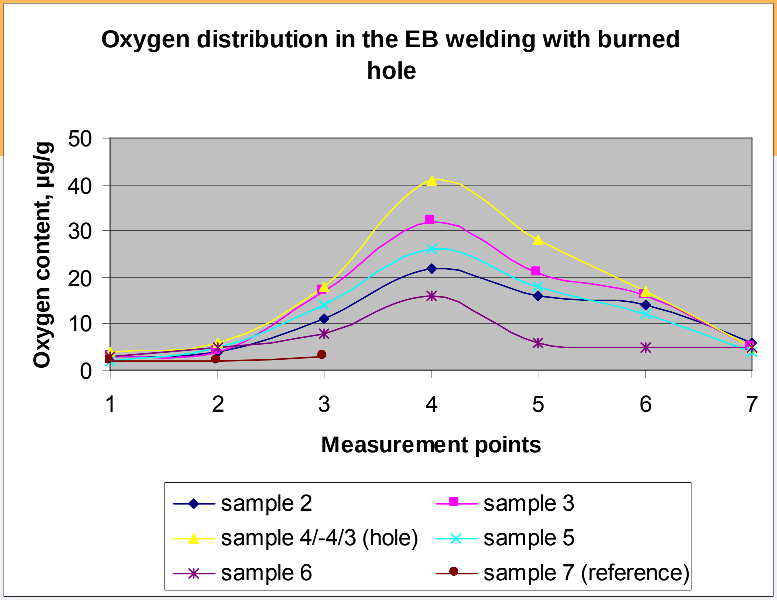
RRR in the welding seam of the welded sample RRR=485

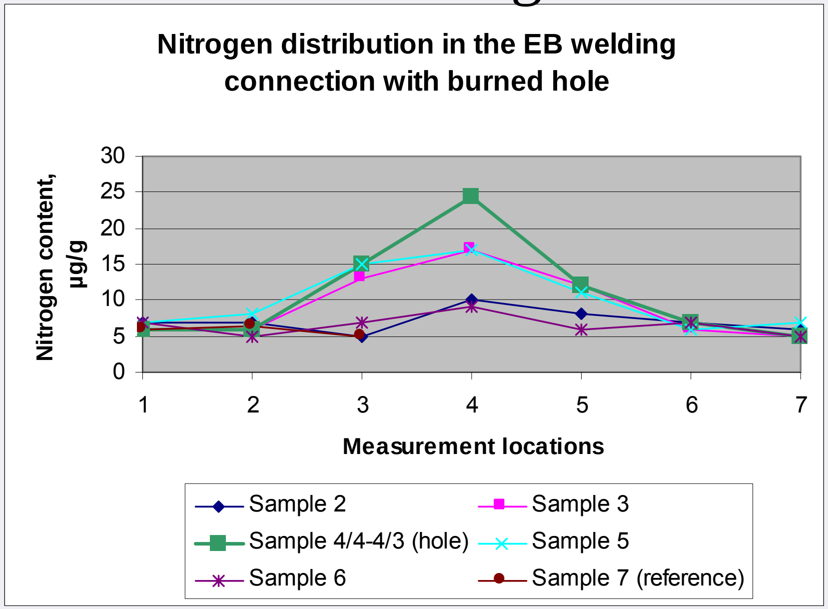
EB burned through hole

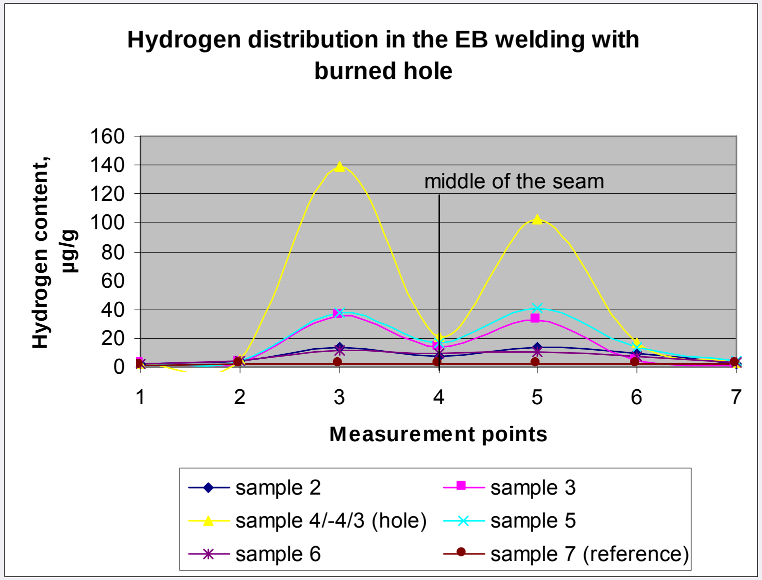
Thank you to F. Schölz for some measurements of gas content



EB welding





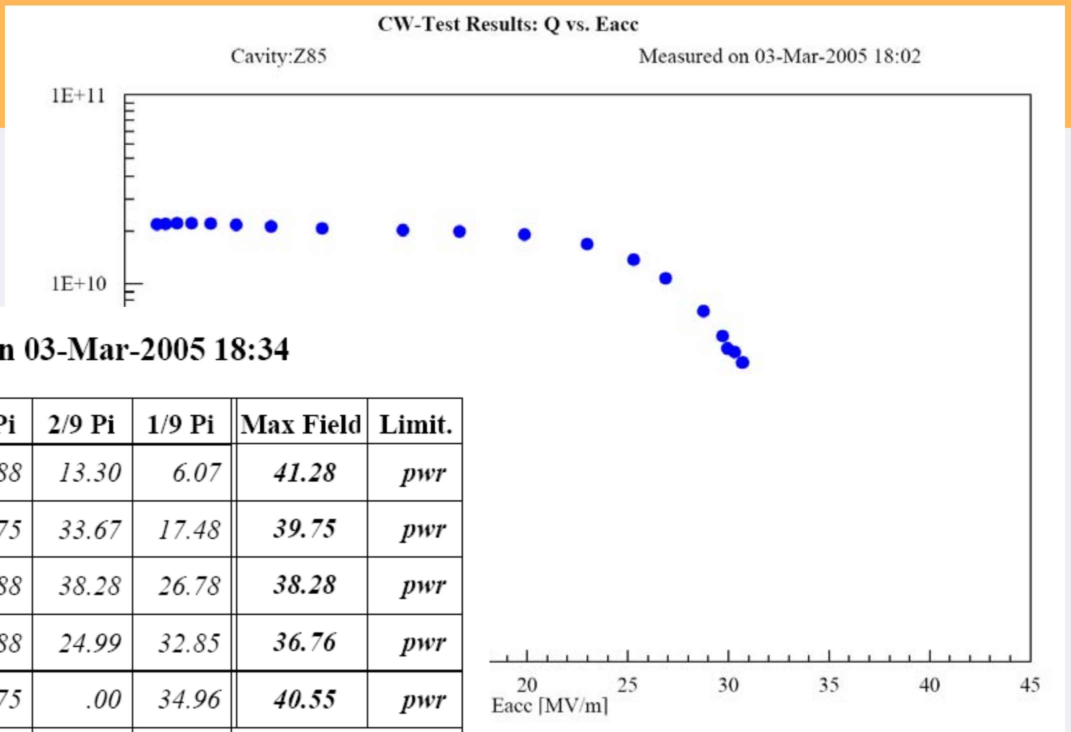


Cavity C43 with repared burned hole

Cavity	Firm	Cells mode meas.	Max Eacc MV/m	Limit	Remark
C43	CERCA	1&9	30,65	bd	
		2&8	27,97	pwr	
		3&7	31,81	pwr	
		4&6	30,21	pwr	
		5	13,18	bd	weld defect

CERCA Cavity, during EB welding was burned a hole, hole repaired by EB welding.
Bad cell identified during mode measurement.
T-Mapping found the quench location. The repaired hole caused a quench at 13 MV/m.

Z85: 190µmEP, 800°C, 2h, 48µm EP, HPR



Mode limits of cavity Z85 measured on 03-Mar-2005 18:34

	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	31.46	41.28	38.10	36.76	29.84	23.32	19.88	13.30	6.07	41.28	pwr
Cell 2&8	31.46	36.30	20.27	.00	19.48	31.42	39.75	33.67	17.48	39.75	pwr
Cell 3&7	31.46	26.94	7.04	36.76	36.61	12.41	19.88	38.28	26.78	38.28	pwr
Cell 4&6	31.46	14.33	31.06	36.76	6.76	35.73	19.88	24.99	32.85	36.76	pwr
Cell 5	31.46	.00	40.55	.00	38.96	.00	39.75	.00	34.96	40.55	pwr
Limit	pwr	pwr	pwr	pwr	pwr	bd	pwr	pwr	pwr		

Z85: ZANON repaired the burned through hole with success

During welding of the cell 3 a hole was burn through. The hole was repaired by covering the holes area with previously cleaned piece of Nb and heating them by the defocused EB.

Conclusive remark 1

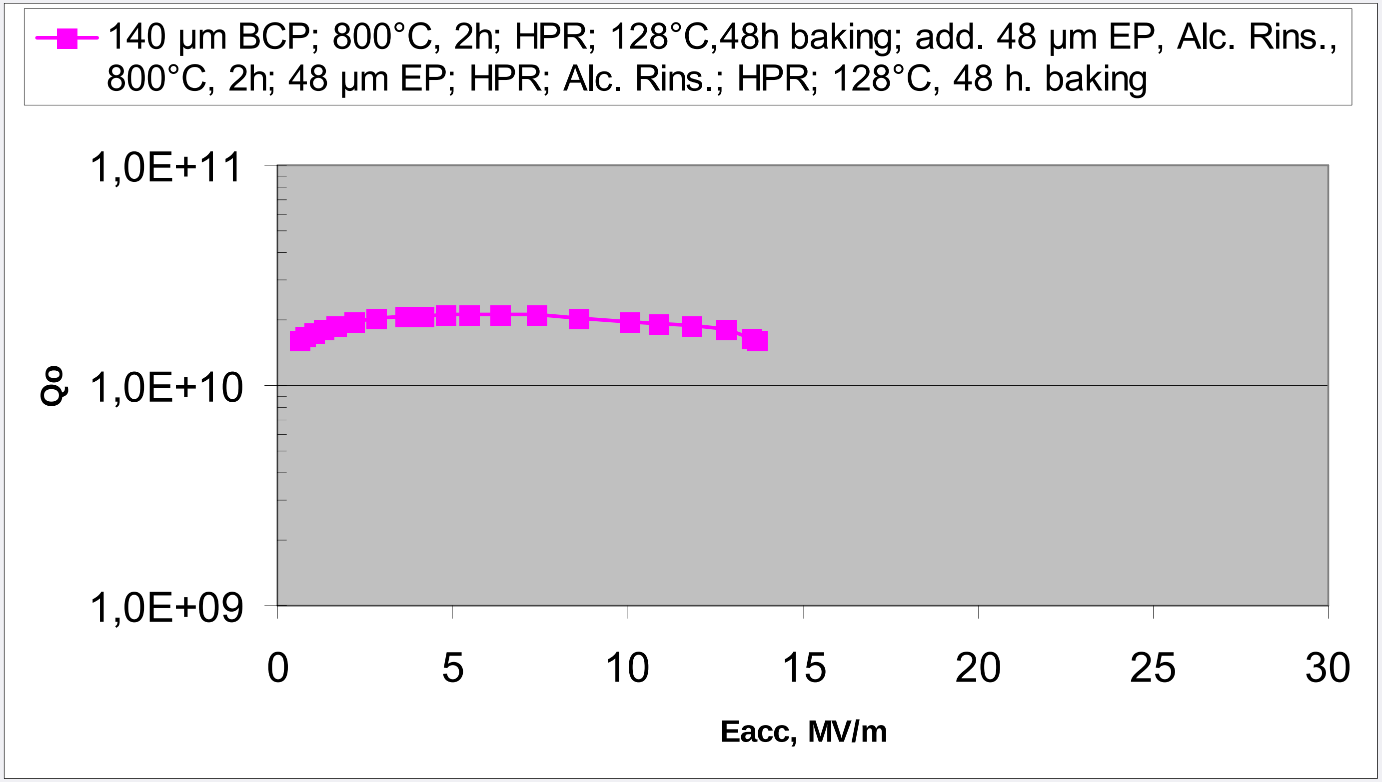
RRR degradation has smaller influence on performance compare to locally imbedded defects in the welding seam (abrasive particles, foreign material inclusions etc.)

Example: TTF Cavities S7-S12 with contaminated welding seams (Eacc = 11 – 19 MV/m)

Clean preparation and assembly conditions for welding are obligatory

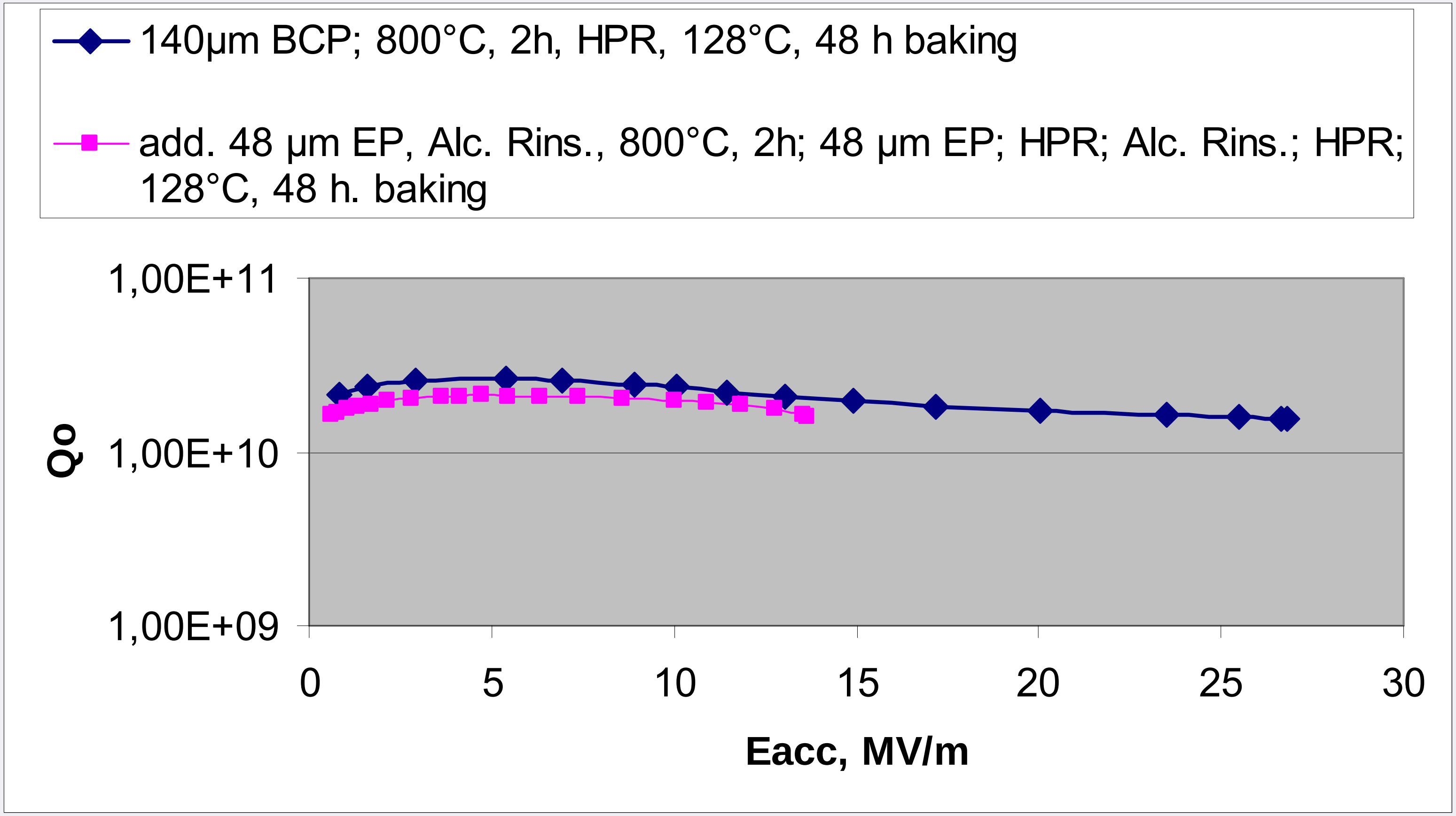
Conclusive remark 2

Not all quenches at low gradients can be explained by welding problems or material problems. Performance degradation can be caused by preparation or processing.



Cavity AC114; Limited by quench, no FE

Conclusive remark 2



AC 114; Performance degradation after additional treatment