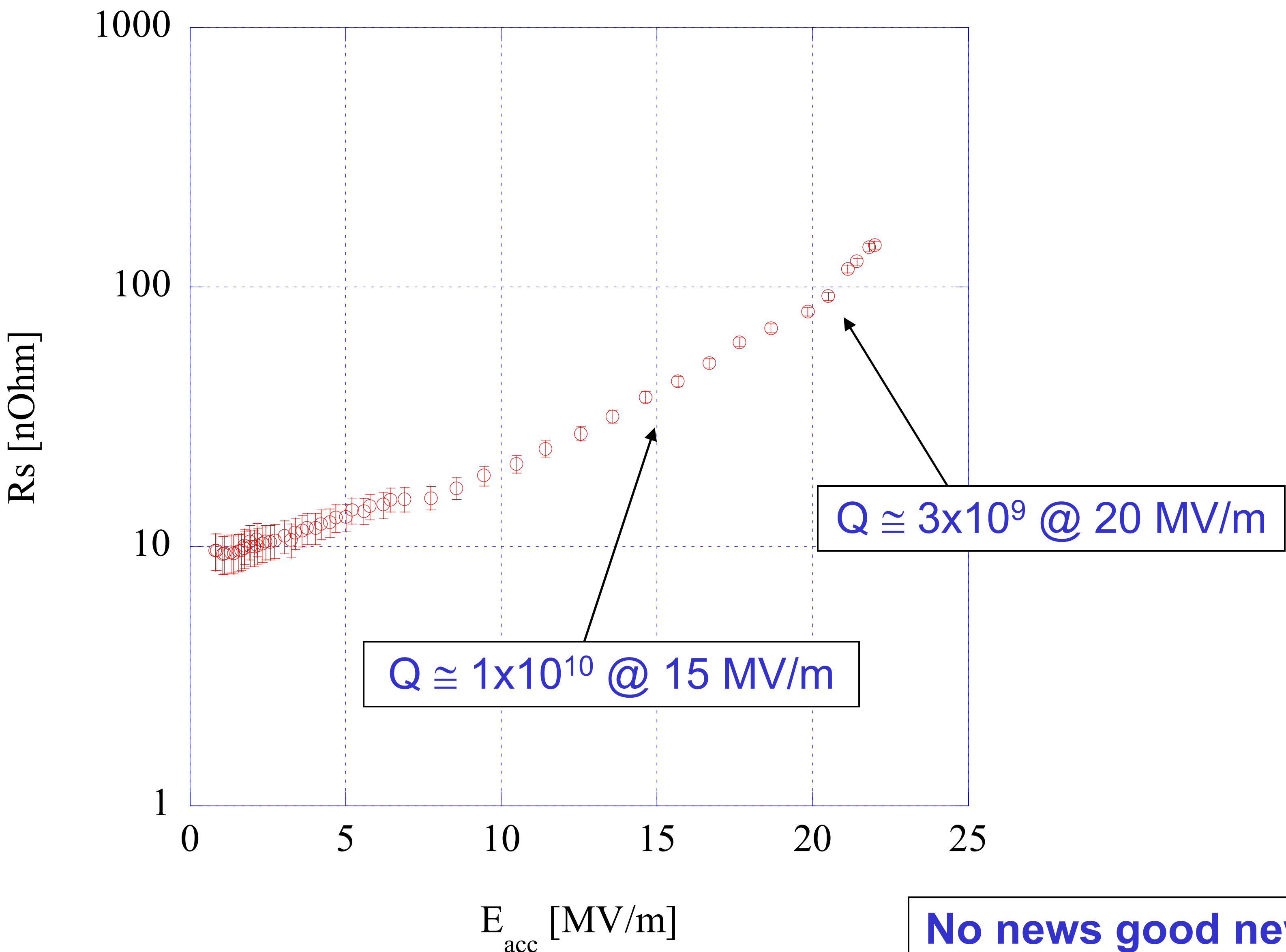
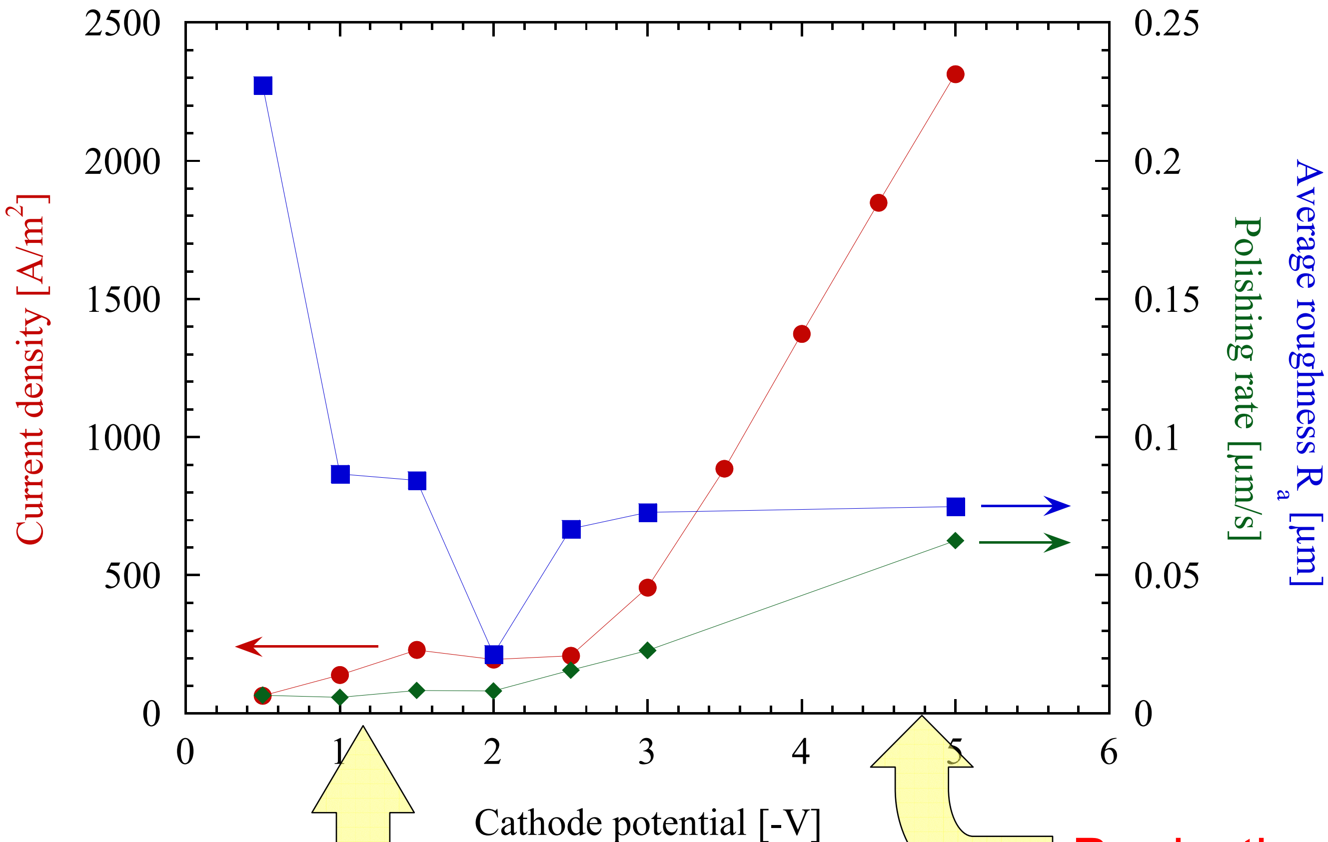
Progress of Nb/Cu Technology With 1.5 GHz Cavities

S. Calatroni
E. Barbero Soto
C. Benvenuti
L. Ferreira
H. Neupert

- Progress with copper electropolishing
- Substrate studies
  - Angle of incidence
  - Thermal impedance
  - Aluminium cavity
- Hydrogen studies
- Conclusions



No news good news?

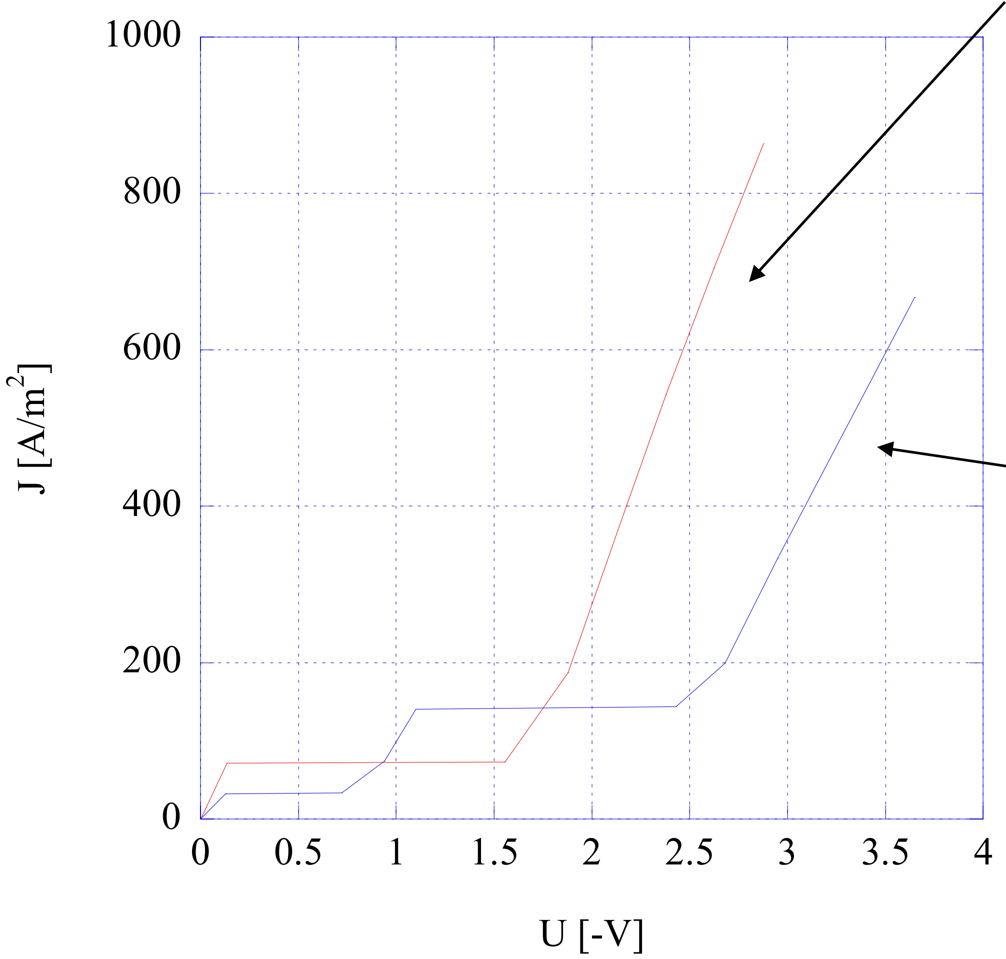


The window of optimum polishing parameters is rather narrow.

Reproducing these parameters over the entire surface of the cavity cell needs further R&D

Production of O_2 bubbles!

Production of $Cu(OH)_2$ on the surface!



Polarisation curve for standard bath

H_3PO_4 (55%) + $C_4H_{10}O$ (45%)

Cu 15 g/litre, conductivity 30 mS/cm

Resistance: ~ 0.1 Ω diffusion layer +
~ 0.1 Ω bath volume

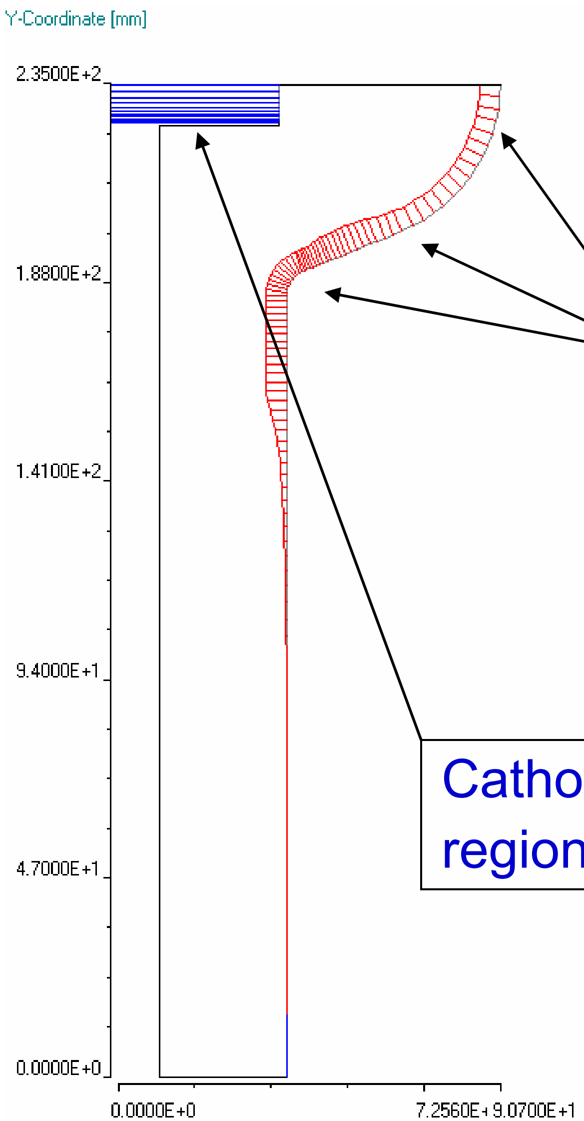
Polarisation curve for aged bath

std. + H_2O (10%)

Cu 25 g/litre, conductivity 110 mS/cm

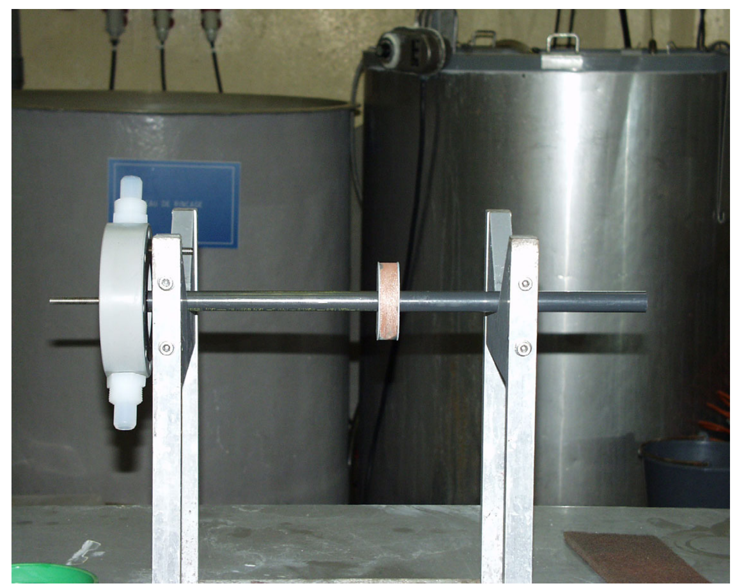
Resistance: ~ 0.1 Ω diffusion layer +
~ 0.03 Ω bath volume

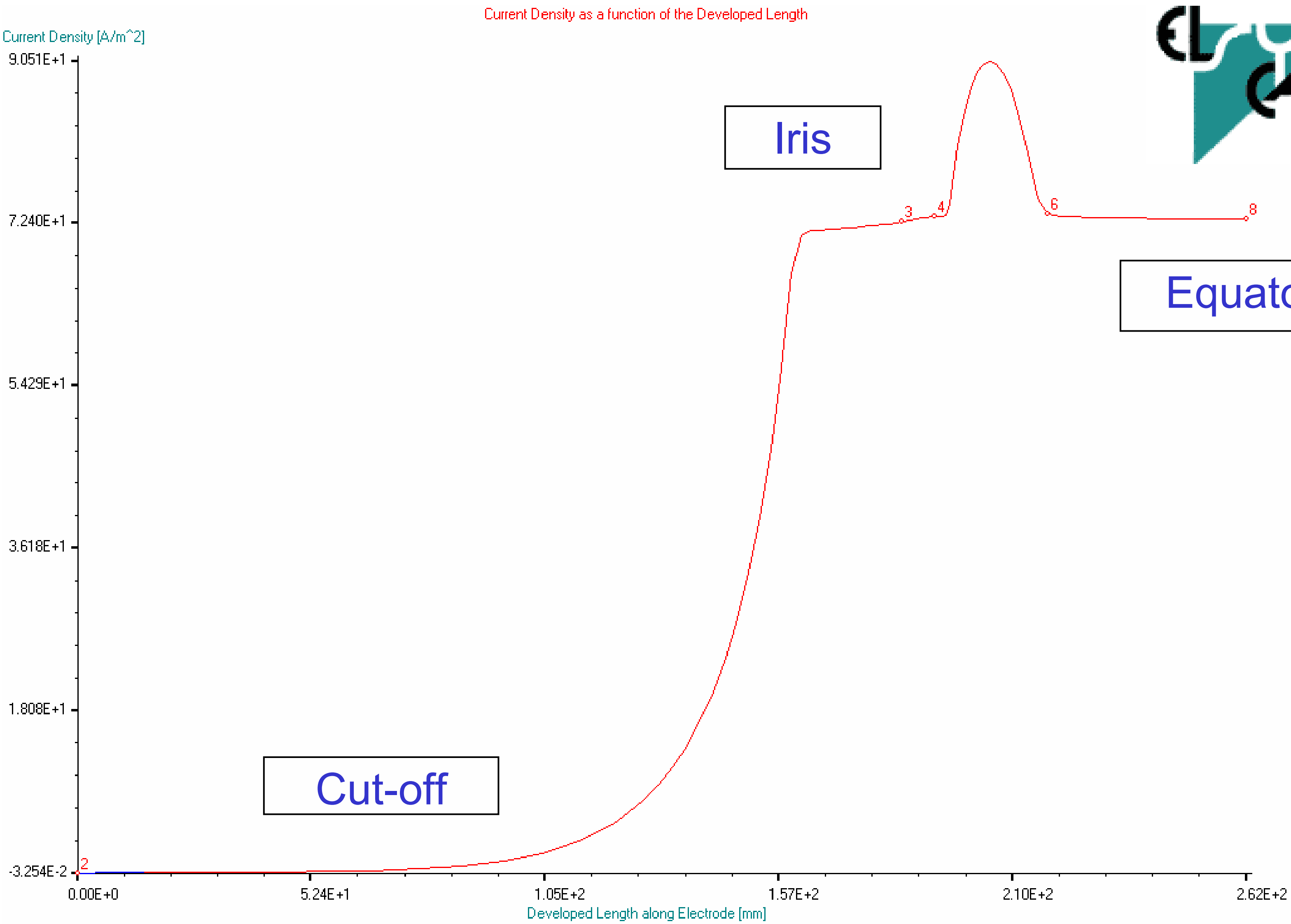
Numerical modelling of the cathode by simulation of the entire EP process with the Elsy 2D/3D computer code (www.elsyca.be)



Current density is uniform over all the cell surface

Cathode active region



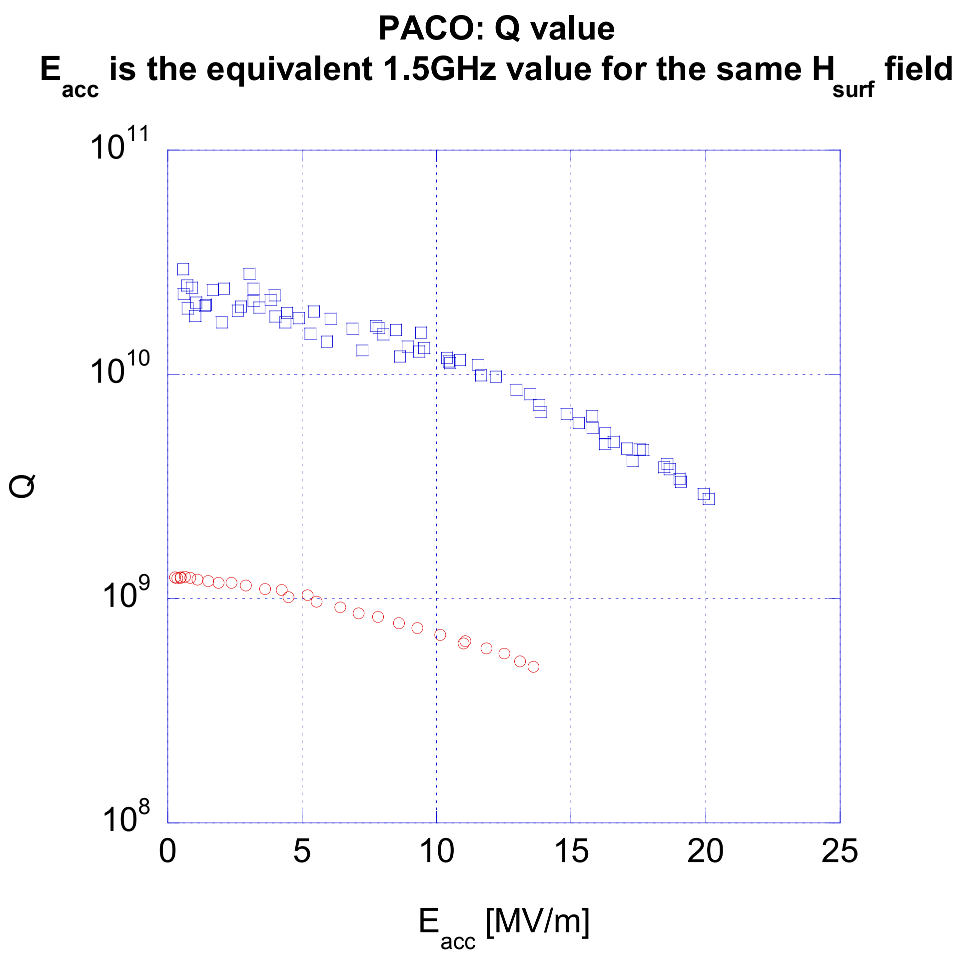

Current Density as a function of the Developed Length
Current Density [A/m^2]
9.051E+1
7.240E+1
5.429E+1
3.618E+1
1.808E+1
-3.254E-2
0.00E+0
5.24E+1
1.05E+2
1.57E+2
2.10E+2
2.62E+2
Developed Length along Electrode [mm]
Iris
Equator
Cut-off
2
3
4
6
8

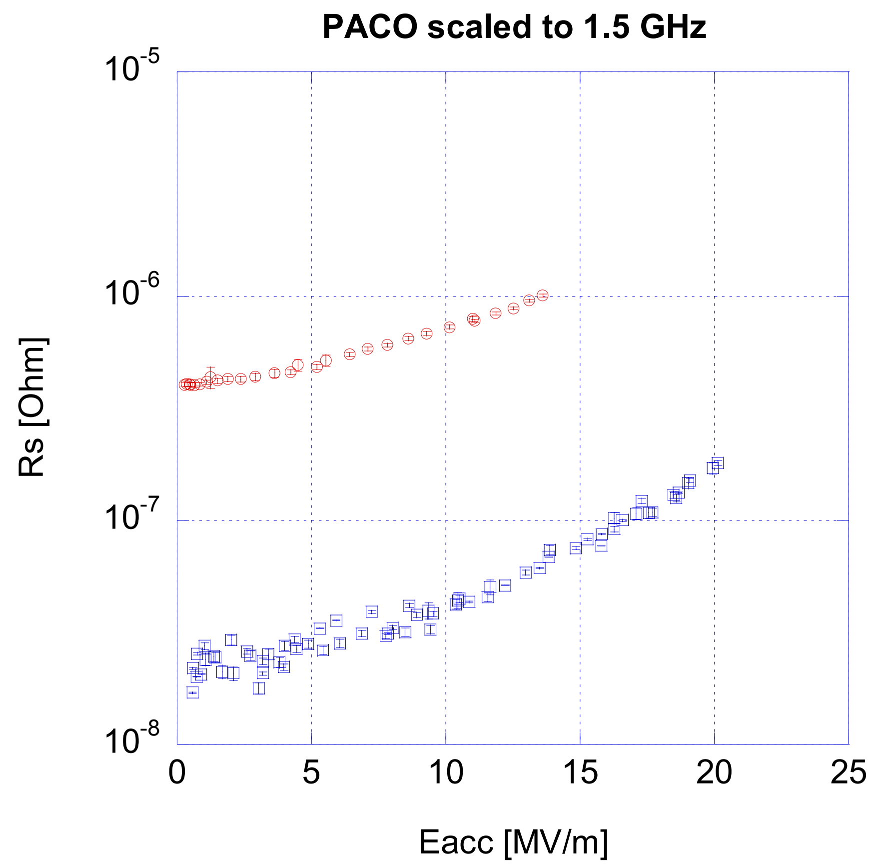
Electropolishing is now performed vertically. No gas bubbles are developed since all the cell surface is polished at the plateau.

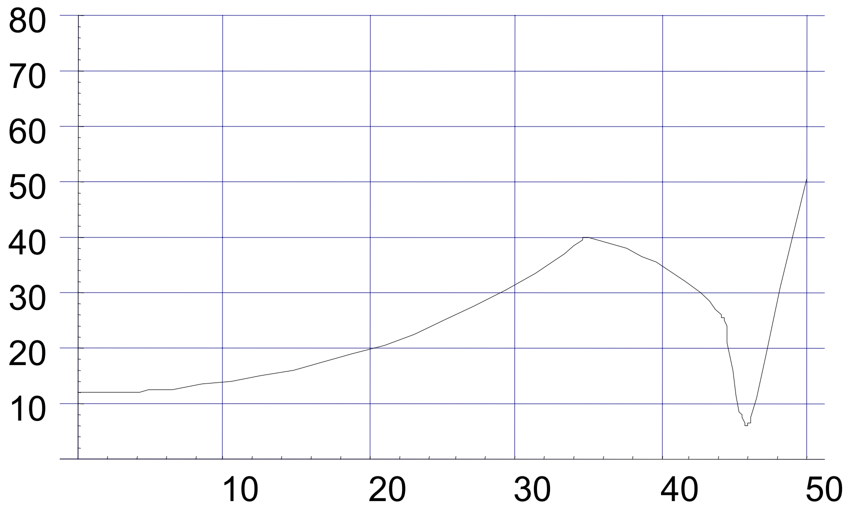
No longer problems of stabilisation time like for horizontal polishing with the cavity rotating and half-filled.

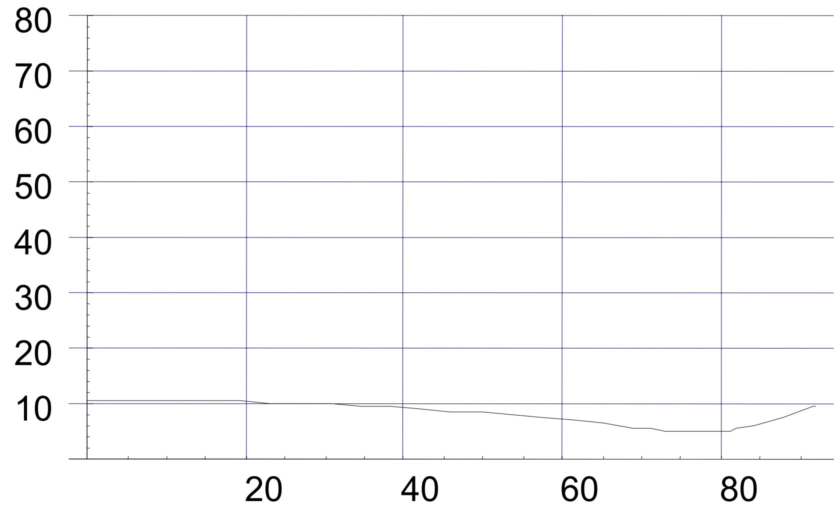
Easier operation

Thanks to: V. Palmieri, G. Gemme, R. Parodi


PACO: Q value
E_{acc} is the equivalent 1.5GHz value for the same H_{surf} field
10^{11}
10^{10}
10^{9}
10^{8}
Q
0
5
10
15
20
25
E_{acc} [MV/m]


PACO scaled to 1.5 GHz
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Rs [Ohm]
0
5
10
15
20
25
Eacc [MV/m]

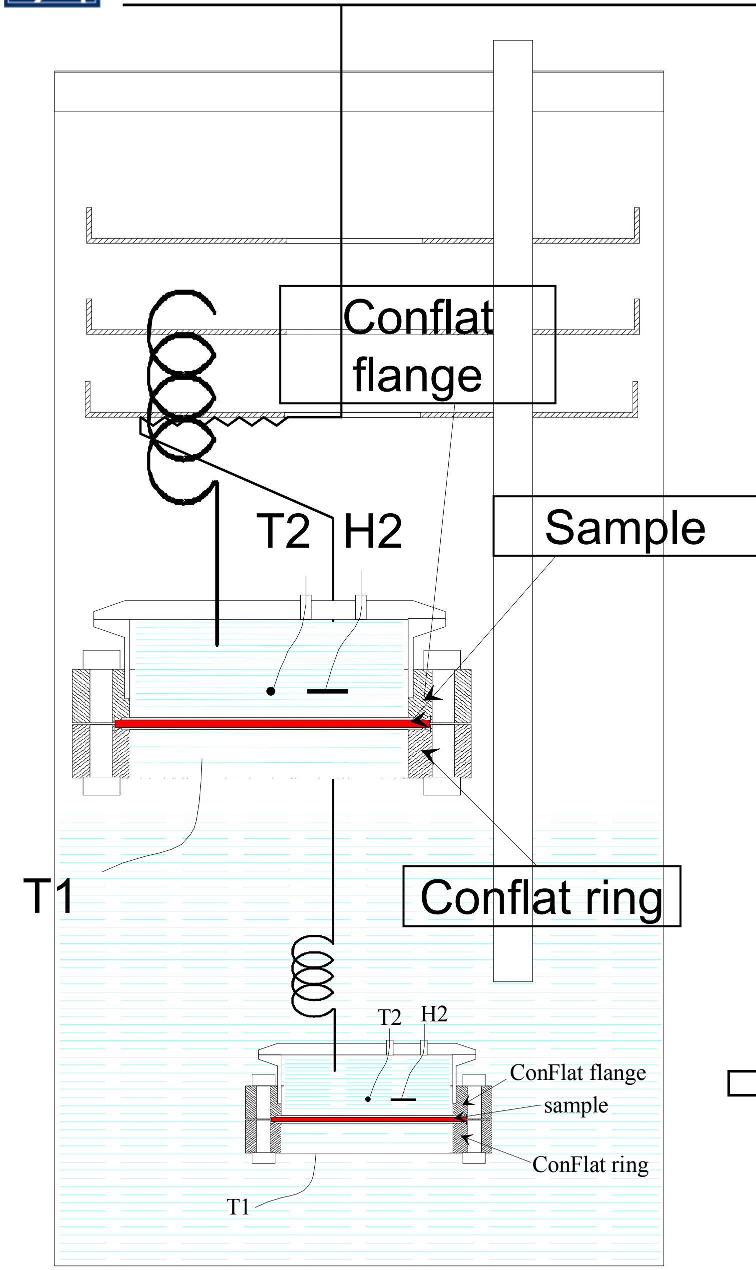




Standard 1.5 GHz cavity

PACO cavity

Average incidence angle of the Nb coating (0º means perpendicular). The abscissa is the length in mm along the cavity axis



The overall thermal impedance has been measured for pure Nb and Cu, and for Nb/Cu and Nb/Nb films, on 2-mm thick disks.

Cu (RRR=100) EP	4300 ± 200 $Wm^{-2}K^{-1}$
Cu EP + 1.5 µm Nb	4100 ± 200 $Wm^{-2}K^{-1}$
Nb (RRR=180) EP	1200 ± 200 $Wm^{-2}K^{-1}$
Nb EP + 1.5 µm Nb	1000 ± 200 $Wm^{-2}K^{-1}$

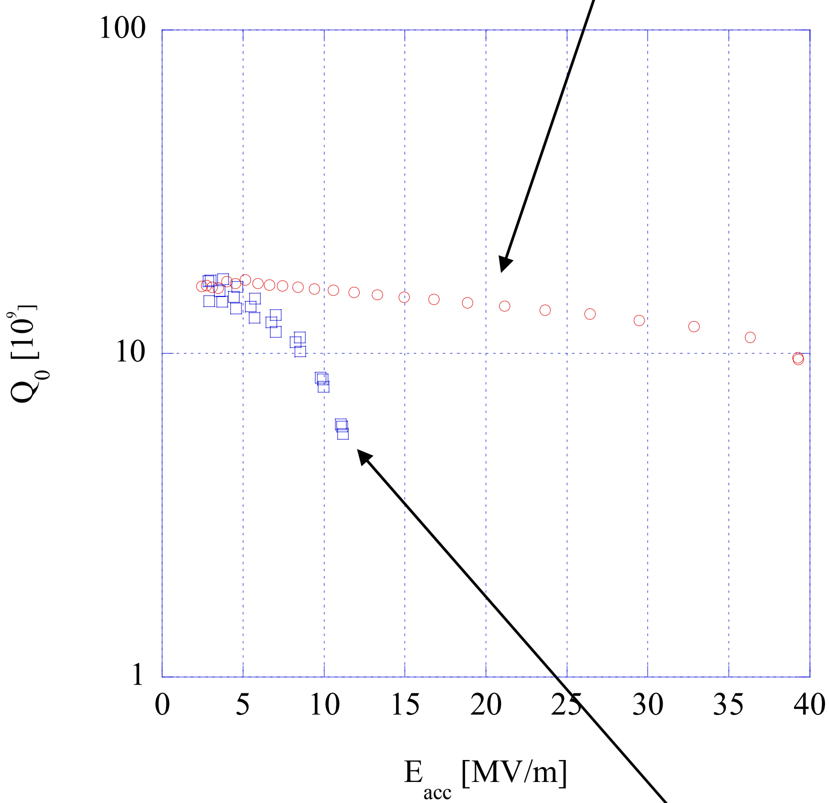
Nb (RRR=670)(extrap.) 2500 ± 200 $Wm^{-2}K^{-1}$

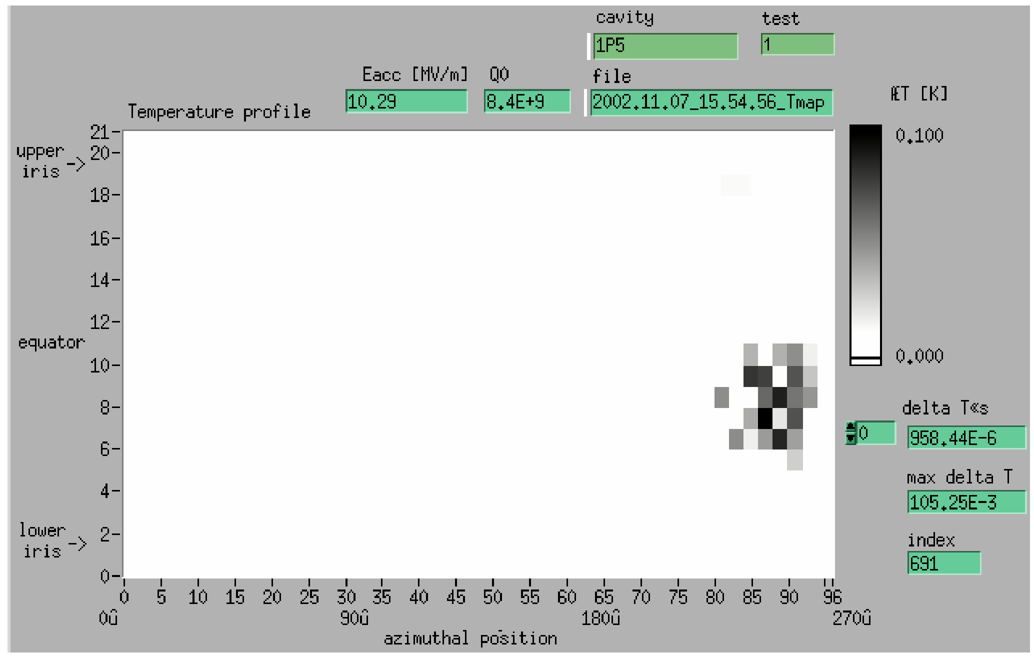
(Still lower than Nb/Cu, but Nb cavities performs better at high field !!)

The thermal impedance of the film (if any) has no effect

Thanks to: G. Vandoni, J-M Rieubland, L. Dufay

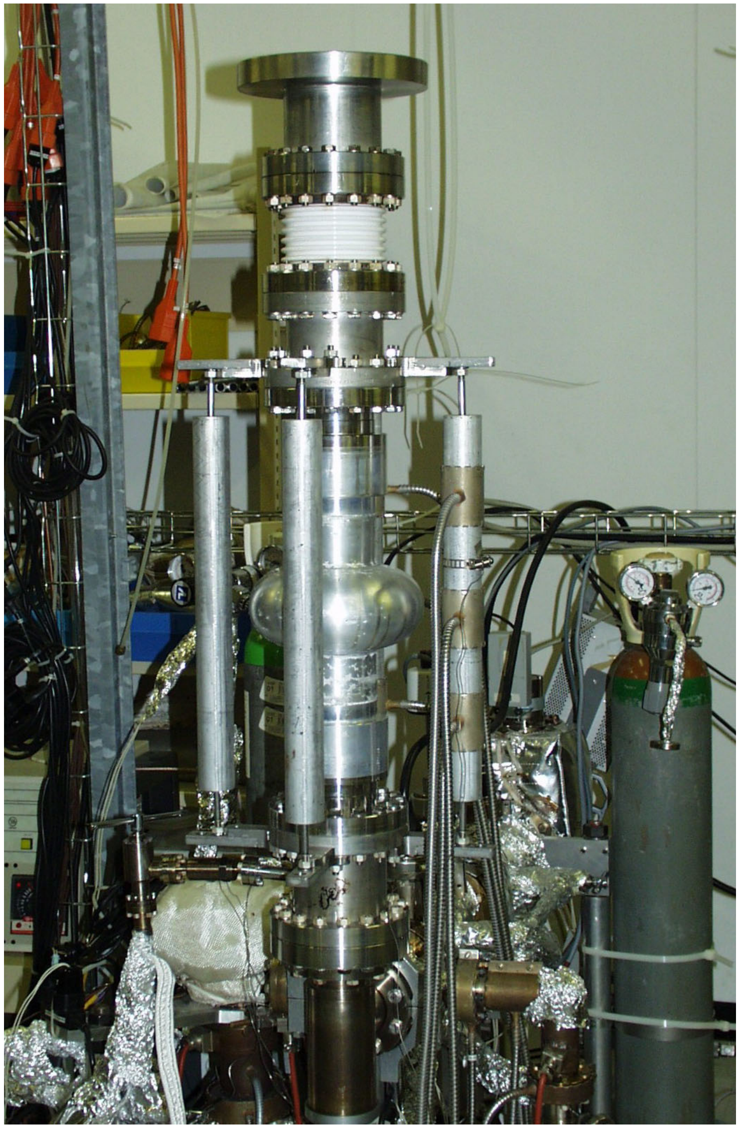
1p5.1 Nb bulk cavity





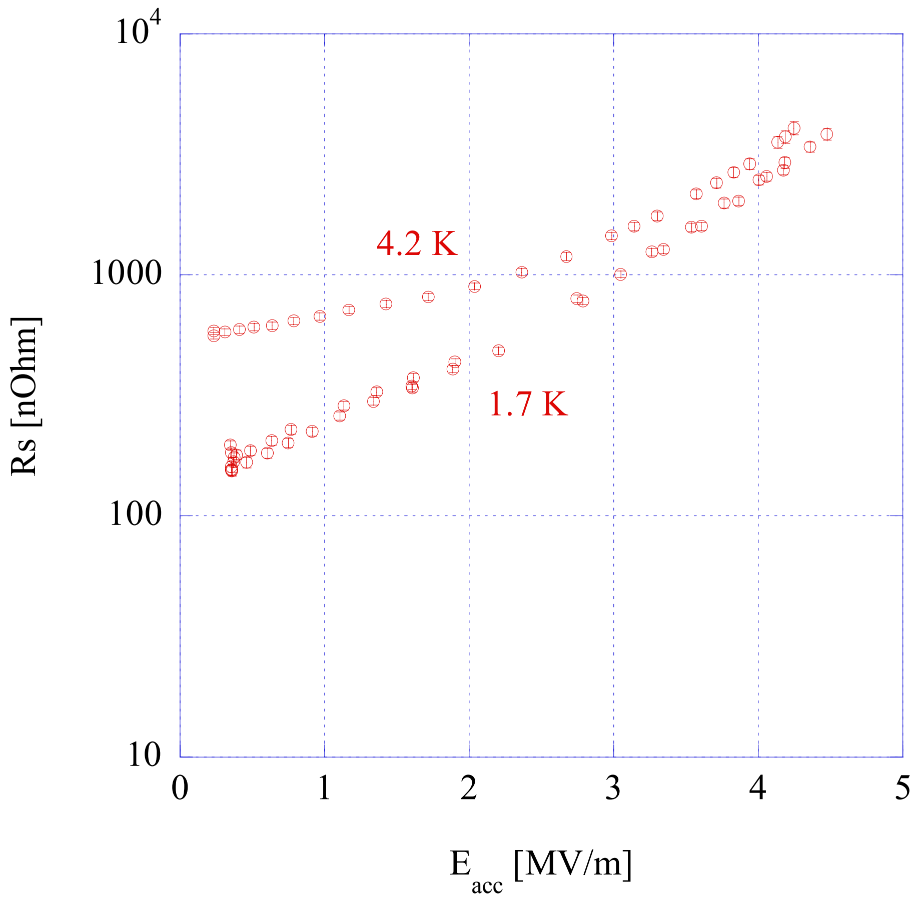
1p5.2 Nb/Nb (quench limited)

Thanks to: V. Palmieri, D. Reschke, R. Losito

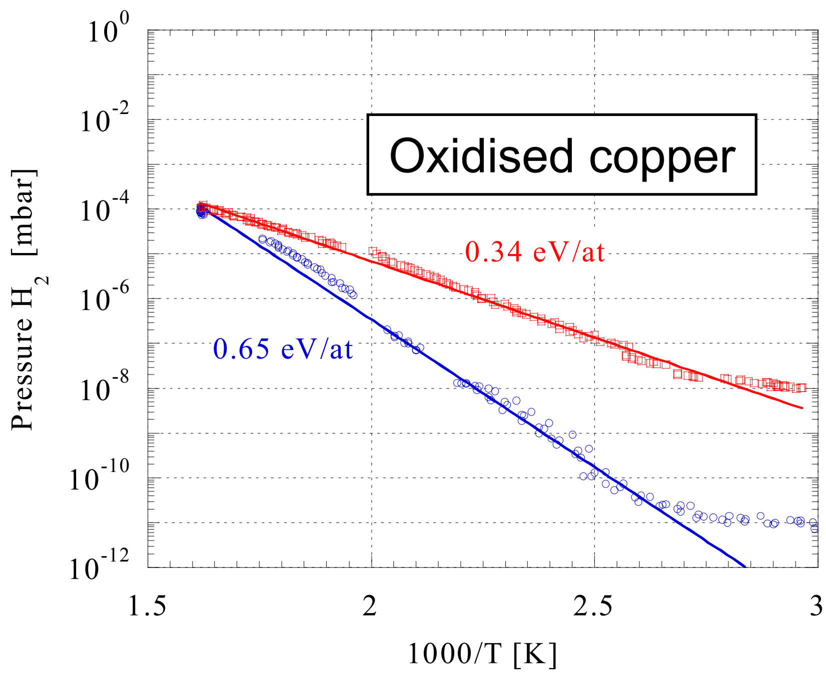


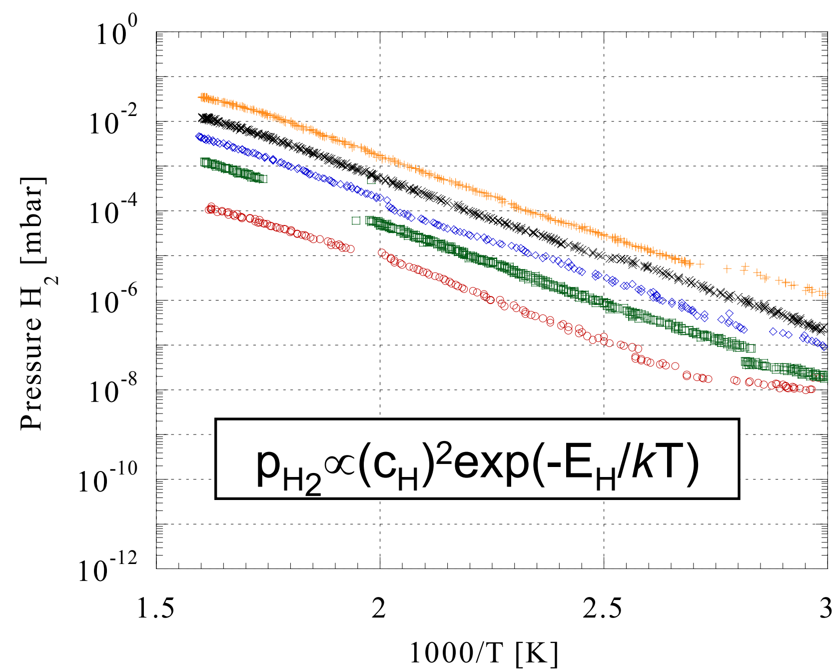
Al 99.999% purity: 10X thermal conductivity of Cu at 4.2 K

Spinning + chemical polishing + coating



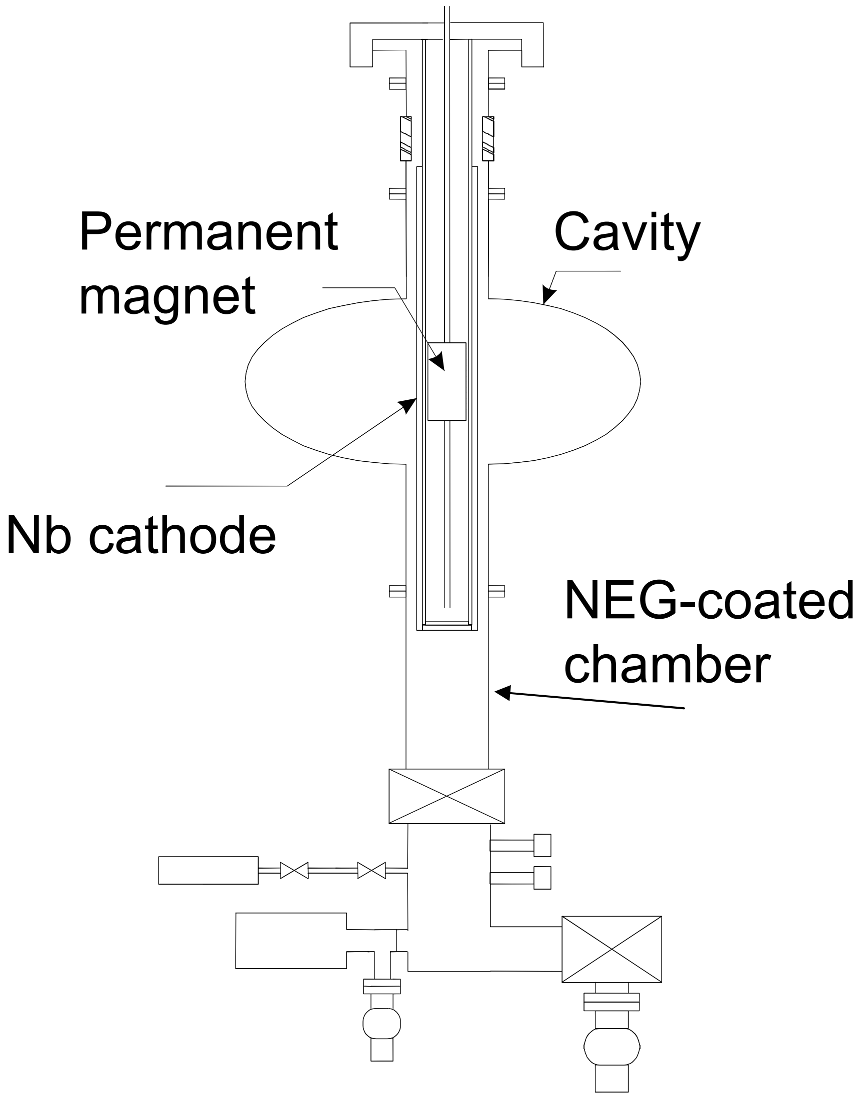
Thanks to: V. Palmieri, G. Lanza



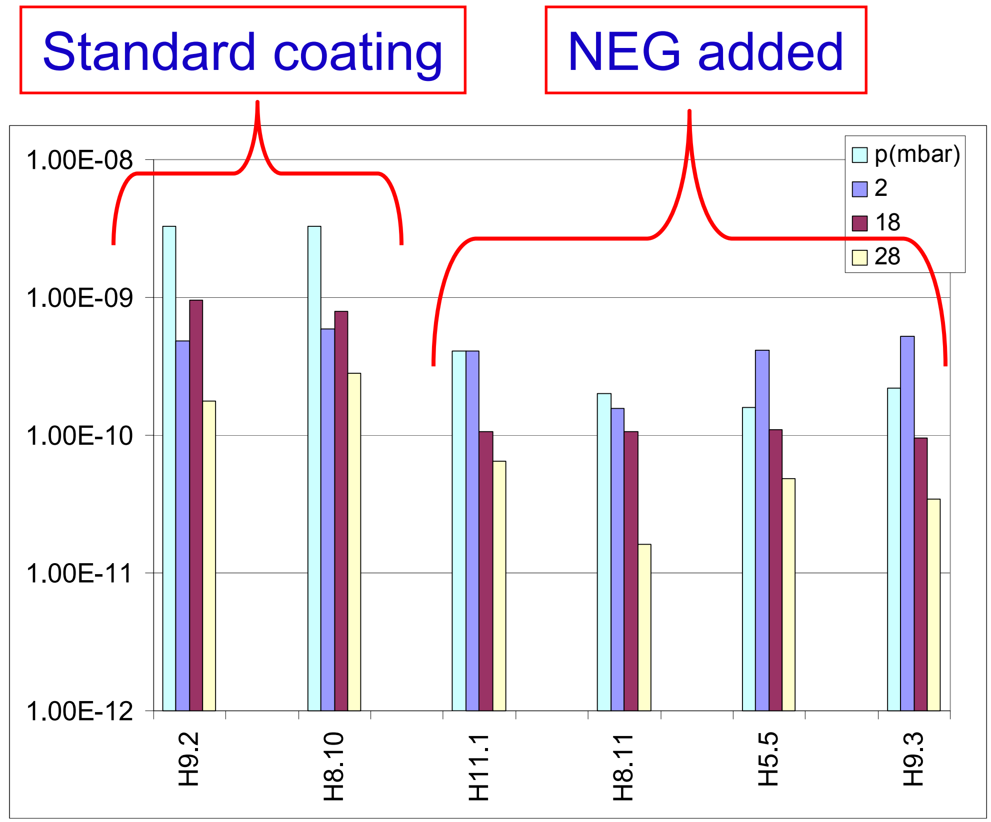


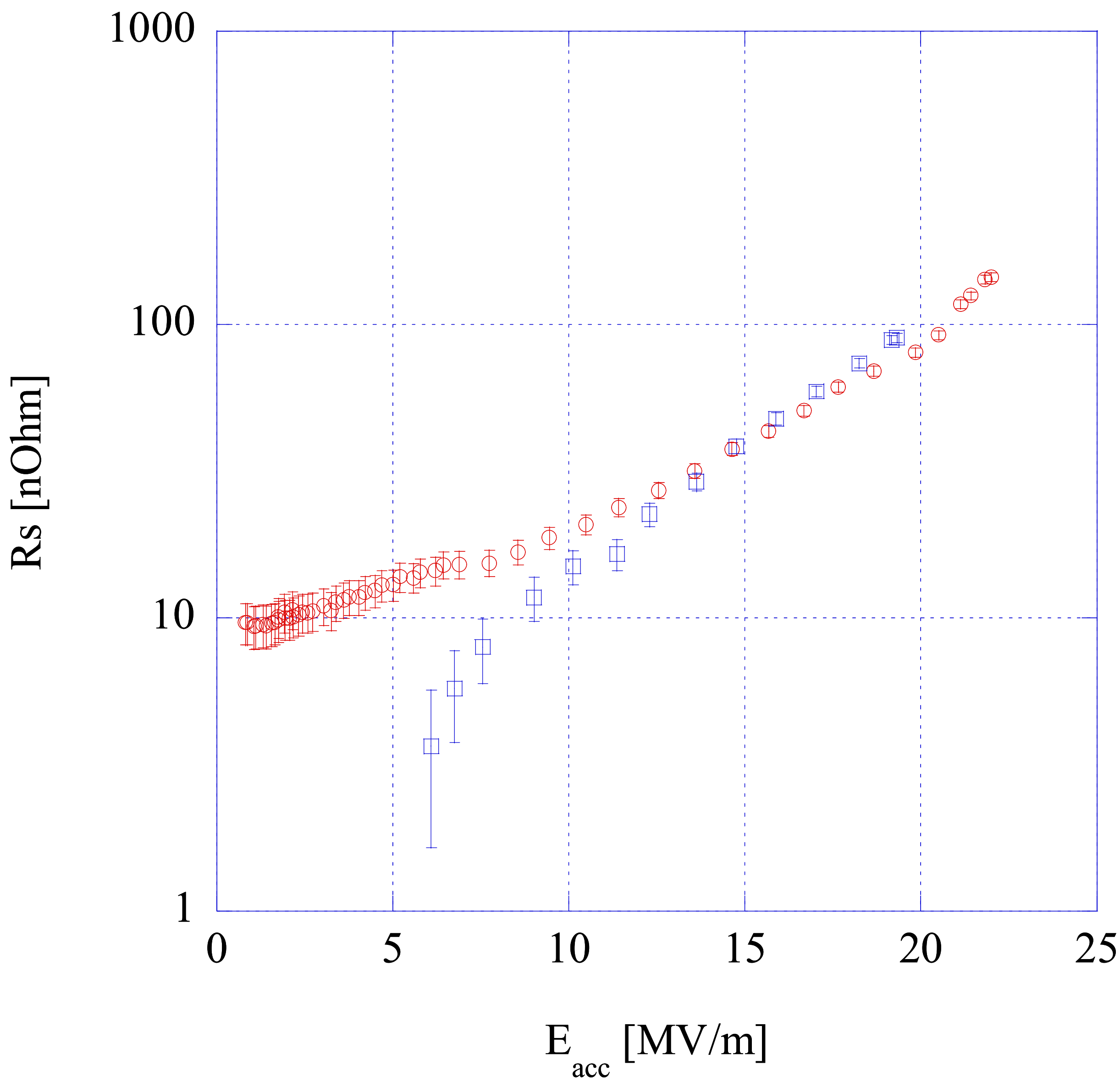
The hydrogen content and its binding energy with the lattice can be measured with isosteric cycles and successive injections of known quantities of hydrogen.

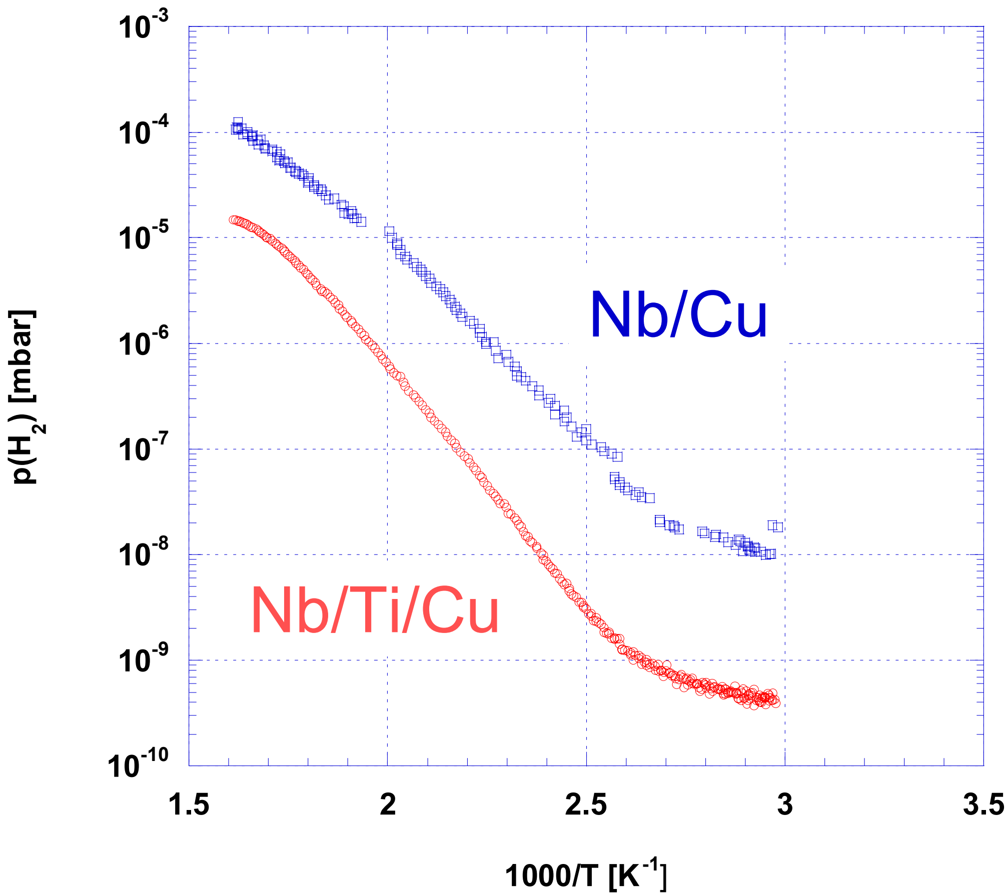
Oxidised copper:	400±200 ppm	340±10 meV/at
Oxide free:	1000±200 ppm	320±10 meV/at



In order to reduce hydrogen, a NEG (TiVZr) – coated pump has been added to the coating system.



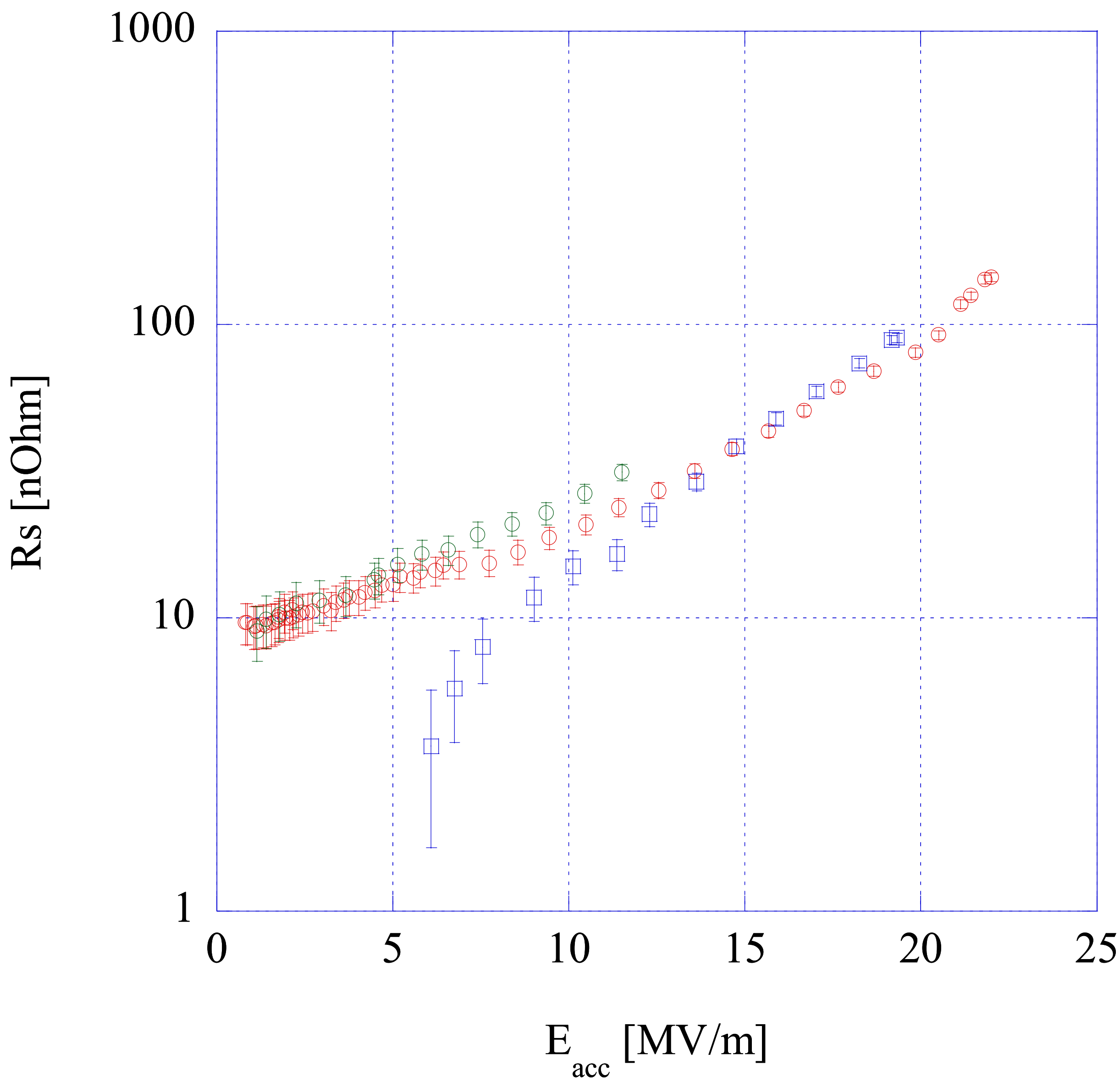

1000
100
10
1
Rs [nOhm]
0
5
10
15
20
25
E acc [MV/m]



$p_{H_2} \propto (c_H)^2$ --> Hydrogen in Nb is 3 times less

In order to reduce hydrogen, a Ti underlayer has been deposited onto copper, prior to Nb deposition.

The H_2 equilibrium pressure has been measured, in order to verify that hydrogen is indeed reduced


1000
100
10
1
Rs [nOhm]
0
5
10
15
20
25
E acc [MV/m]

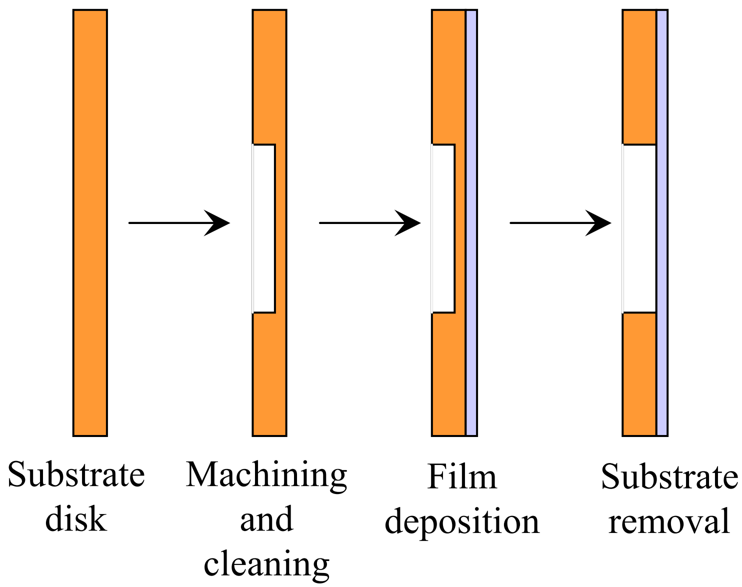
- Electropolishing is well understood, and provides a solid basis for studying the physical origin of the residual resistance increase at high field.

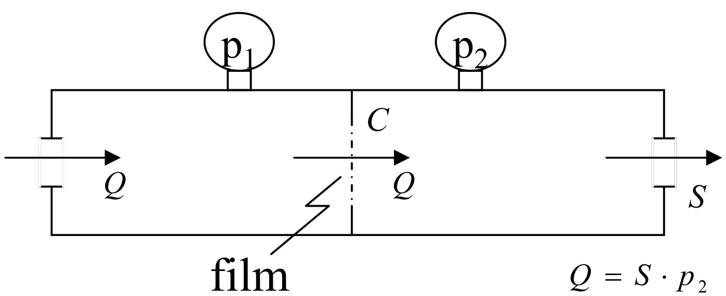
- The angle of incidence of the coating is not an issue
- Thermal barrier between Nb and Cu is not a limitation
- Hydrogen has been decreased: no improvement of RF performance

- Intrinsic film roughness?
- NbO at the surface (preferentially at grain boundaries)?
- Nano-defects in the RF penetration depth?

Measurement of pinholes

Irregularities on the substrate surface ➡ shadowing effect
film inhomogeneities





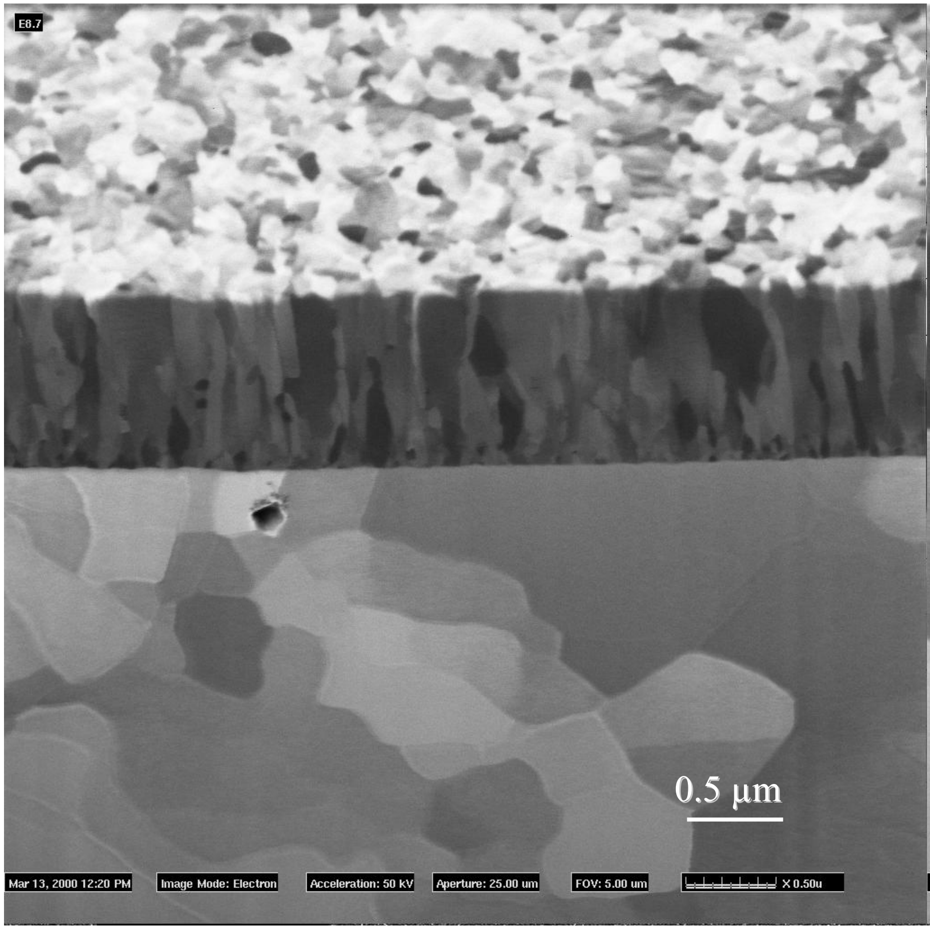
He leak rate experiment

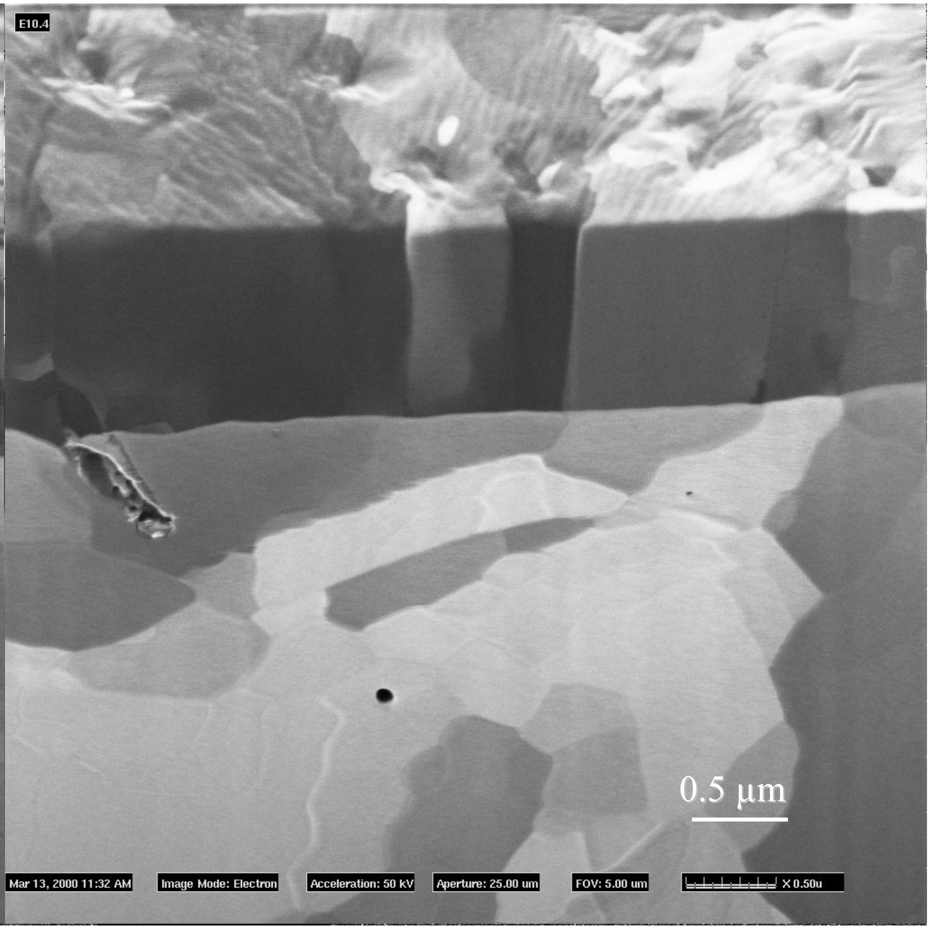
		$\langle\theta_{inc}\rangle$	fraction of leaky film surface
CP	- equator	9°	4.4 ppm
	- (~iris	50°	25 ppm)
EP	- equator	9°	0.1 ppm

Grain size with FIB micrographs

Standard films

Oxide-free films

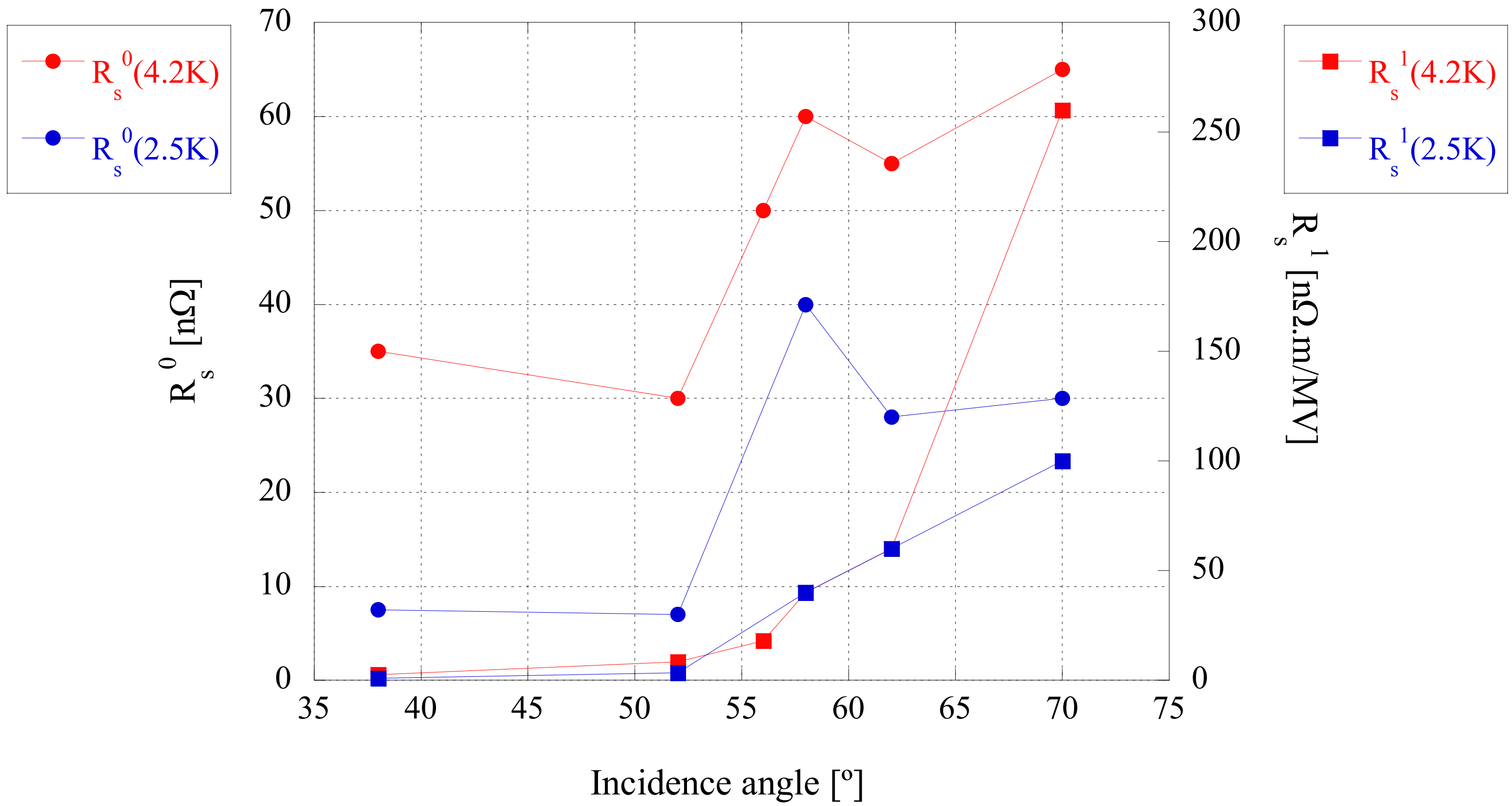




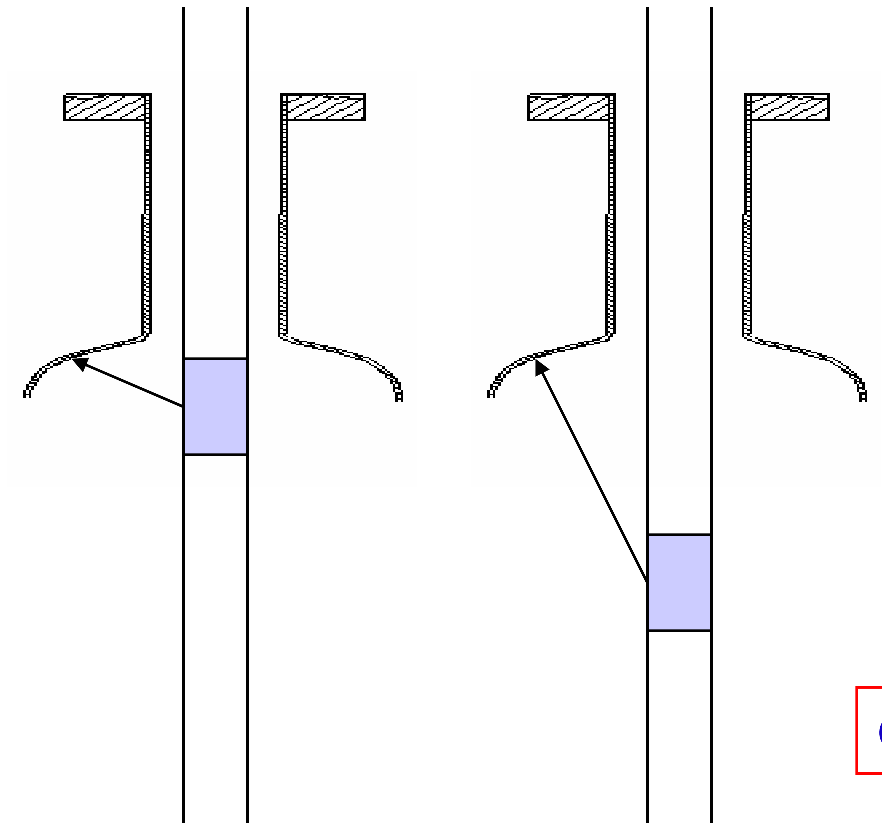
Courtesy: P. Jacob - EMPA

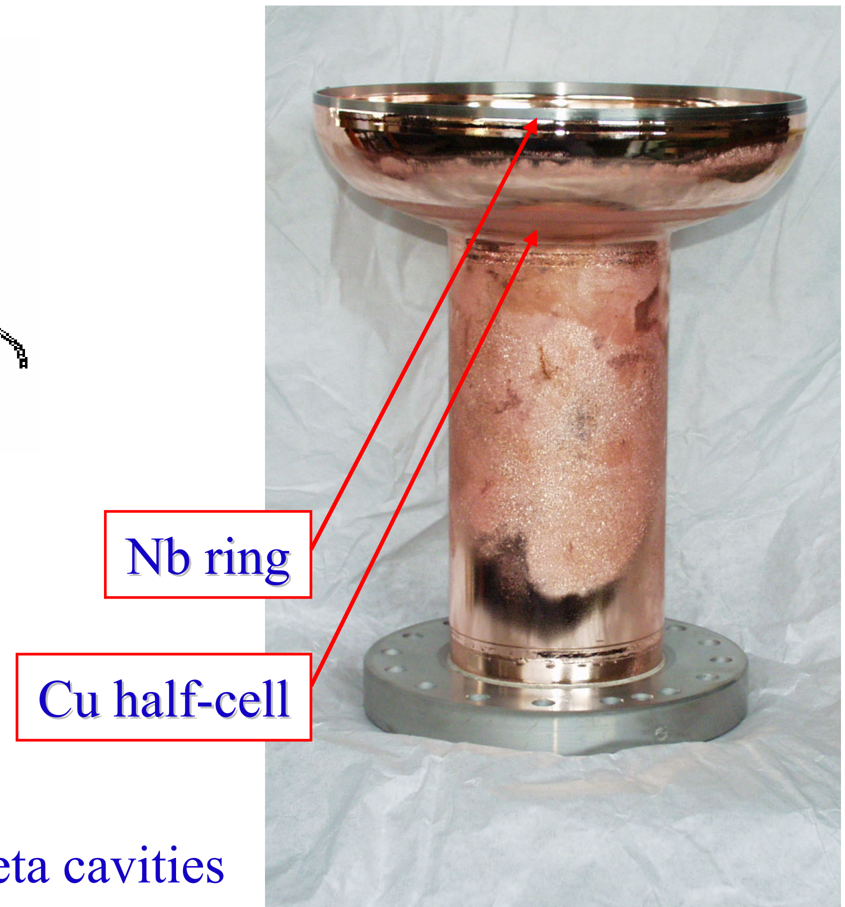
Incidence angle and residual resistance

An issue which is of great interest also for low-ß cavities, is the correlation between the incidence angle of the film and the residual resistance



Digression: new ideas for low-beta cavities coating

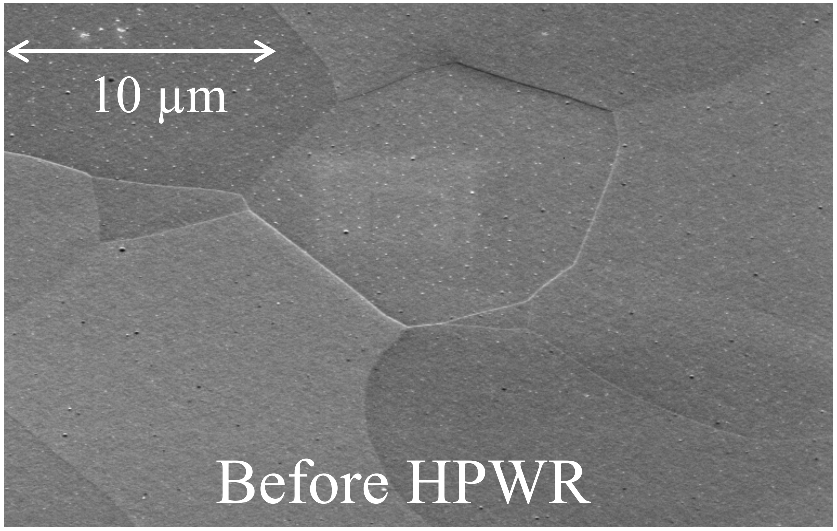


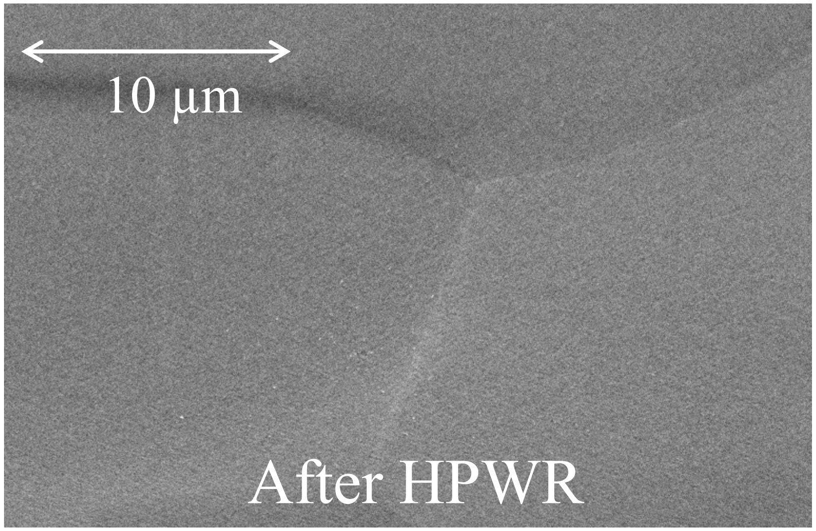


Problem: coating incidence angle in low-beta cavities

Solution: coat at favourable angle before welding

HPWR smoothens Nb surface





Bulk Nb - EP with KEK bath

HPWR smoothens the grain boundaries (2001 results)