



# Surface treatments of PIP-II single cell MB prototype

Michele Bertucci/INFN-LASA

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A Partnership of:

US/DOE

India/DAE

Italy/INFN

UK/UKRI-STFC

France/CEA, CNRS/IN2P3

Poland/WUST

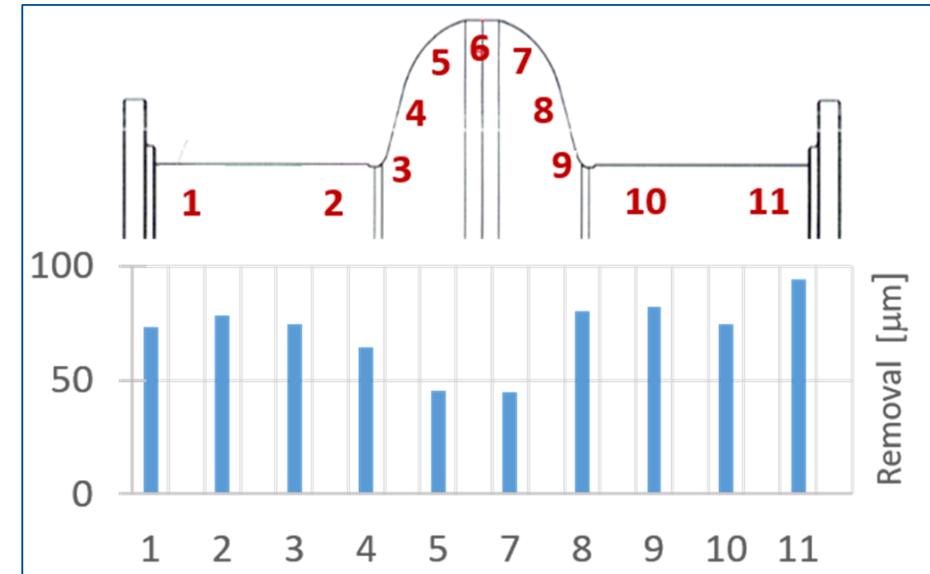


# INFN-LASA Surface treatment validation strategy

- **Single cell cavity prototype** treated with standard XFEL recipe:  
200  $\mu\text{m}$  bulk EP+800°C HT+120°C bake+final cold EP
- Cavity test @ INFN-LASA
  
- **Single cell cavity prototype** retreated with high-Q recipe:  
200  $\mu\text{m}$  bulk EP + 800°C HT + 2/6 N<sub>2</sub> doping @800°C + final cold EP.
- Cavity tested again @ INFN-LASA
- Results are compared with the «standard recipe» ones (and also with FNAL results on single cell LB cavities)
- If qualification values for Eacc, Q<sub>0</sub> are reached, we consider the surface treatment validated for LB single cell cavity
  
- **Multicell cavity prototype** treated with with high-Q recipe, basing on previous results on single cells (thanks to LASA and FNAL experience)
- Cavity tested @ INFN-LASA
- If qualification values for Eacc, Q<sub>0</sub> are reached, we consider the surface treatment validated for LB multicell cavity.

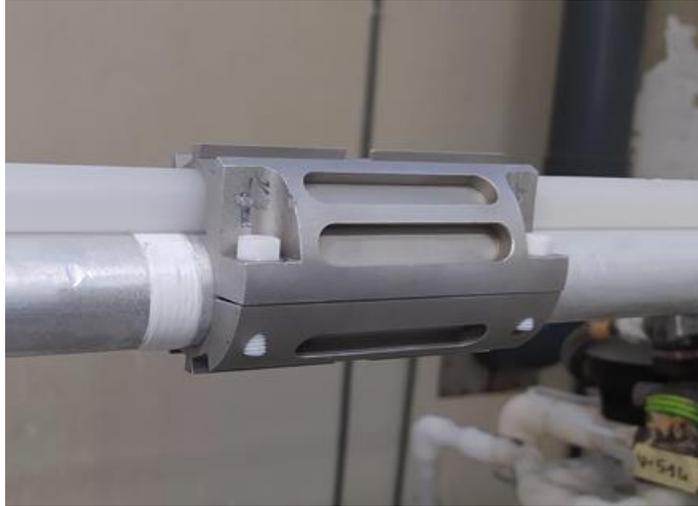
# Single cell cavity: electropolishing optimization

- First trials (40-60  $\mu\text{m}$  each): used to optimize removal, smoothness and iris\equator removal rate
- First attempts made with plain cathode
- **63 mm** average removed thickness [**0.13  $\mu\text{m}/\text{min}$** ]
- **40 A** average current
- **51 kHz** frequency shift. [**0.81 kHz/ $\mu\text{m}$** ]
- Local thickness measured by US probe before and after the treatment. **40 mm** removed near equator vs **80 mm** removed on irises. Removal ratio is  $>2$



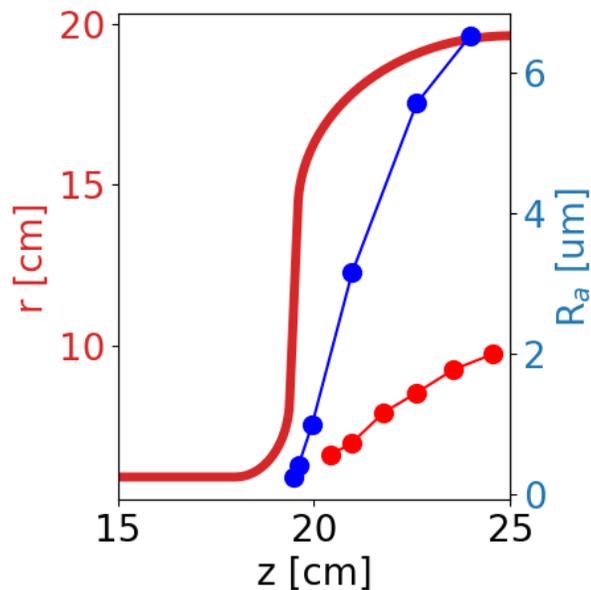
- Improved surface smoothness on beam tubes, irises and walls...
- ...but modest gain in roughness at the equator
- **Removal at equator will be increased by:**
  - **Cathode enlargement**
  - **Temperature setpoint will be reduced so to stabilize the process**

# Single cell cavity: EP optimization

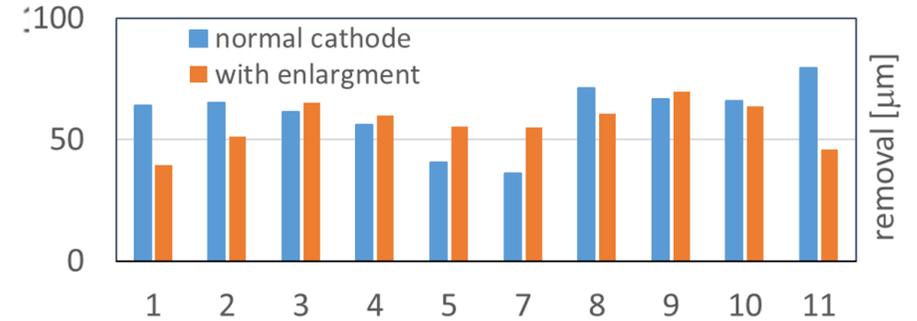
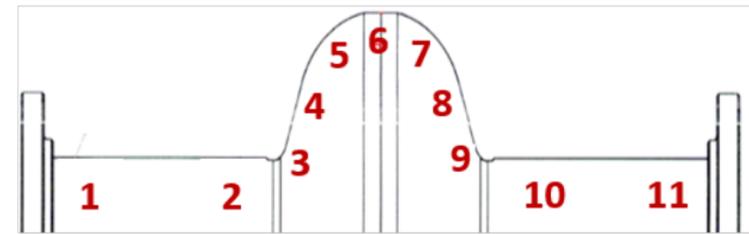
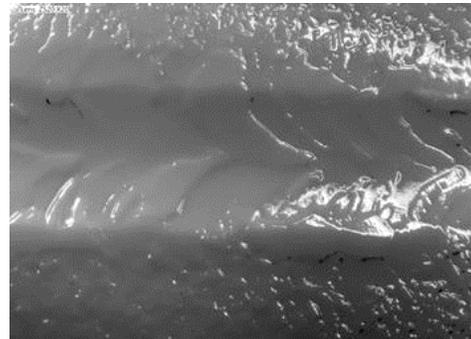


After cathode enlargement installation:

- Average current increases to >45-50 A
- Enhanced removal at equator as measured by US after treatment
- Equator roughness goes from 6  $\mu\text{m}$  to 2  $\mu\text{m}$  after 40  $\mu\text{m}$  EP removal



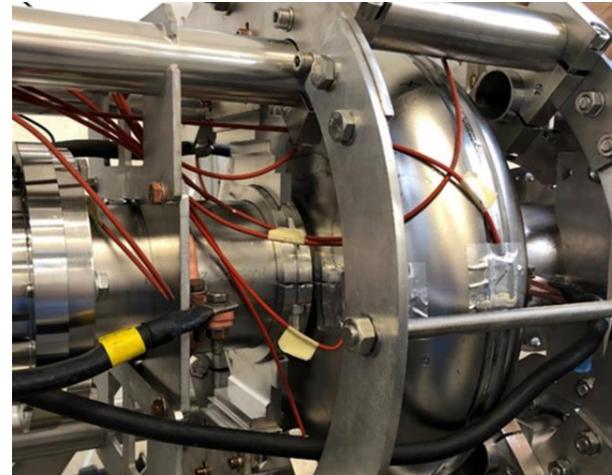
Roughness measurement on replicas by 3D microscope before and after 40  $\mu\text{m}$  EP



US measurement before and after plain cathode EP  
And improved cathode EP

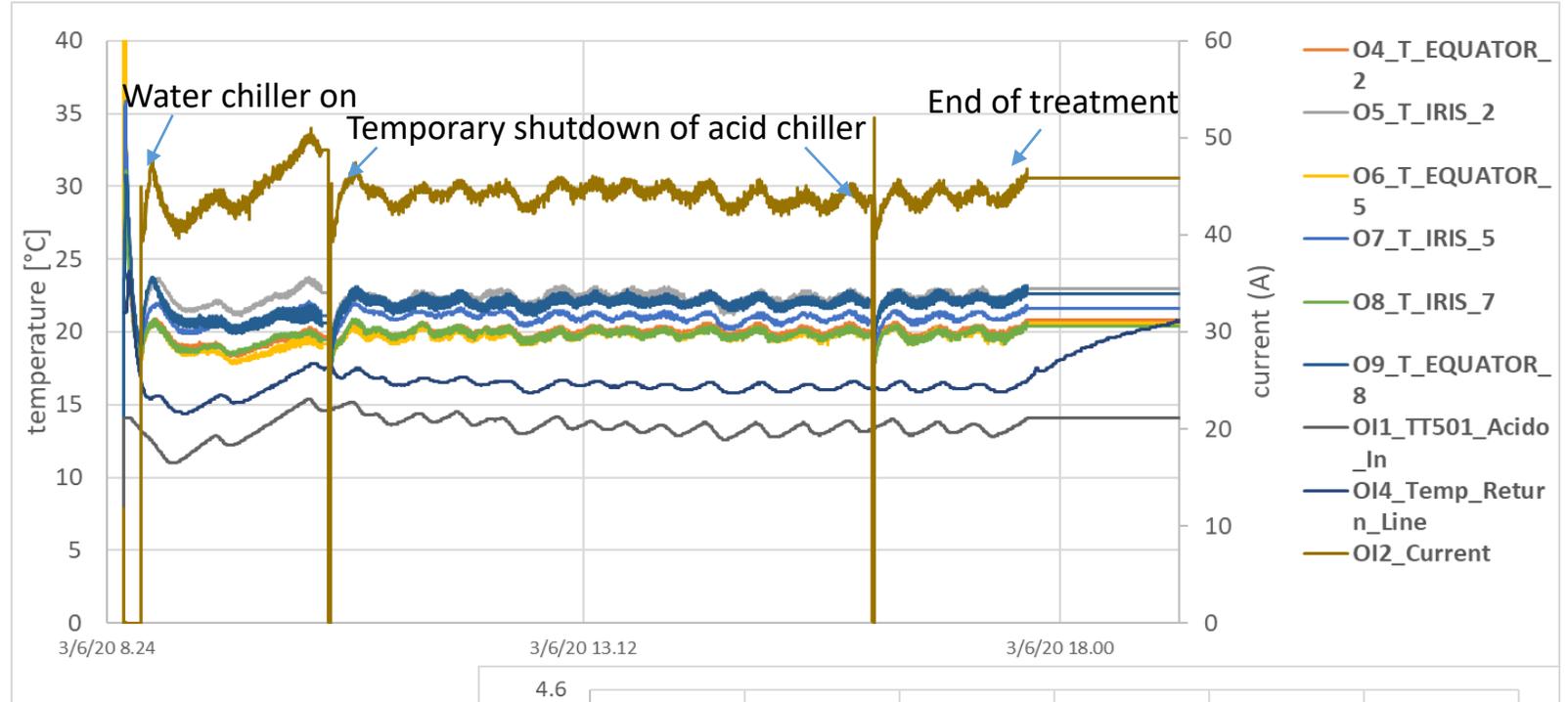
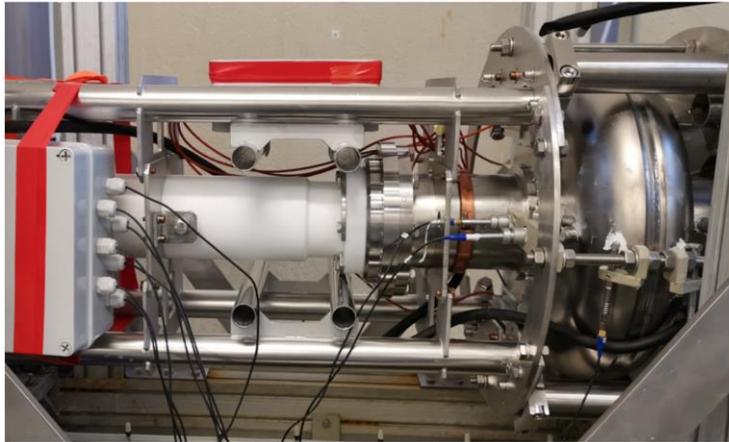
# Single cell Bulk Electropolishing

- The already existing EP plant at E. Zanon (used for XFEL and LCLS-II cavity production) is now optimized for the single cell cavity. The goals are:
  - Good surface finish: smooth surface **everywhere** (roughness  $R_a < 1 \mu\text{m}$ ) so to prevent high field Q slope
  - Control the removal at equators: **essential for final EP after nitrogen doping**. We need iris/equator removal ratio  $< 2$
- Target removal:  $150 \mu\text{m}$  avg.
- Voltage =  $17 \text{ V}$
- Nb initial dilution in electrolyte:  $4.5 \text{ g/L}$
- 50% cathode coverage at beam tubes
- Acid overall throughput:  $6 \text{ L/min}$
- Acid inlet temperature (at beginning of process):  $15^\circ\text{C}$
- Temperature setpoint for chiller:  $20\text{-}21^\circ\text{C}$  avg (then raised to  $21\text{-}22^\circ\text{C}$  avg.), max  $25^\circ\text{C}$  on beamtubes
- Water cooling on beamtubes (if  $T > 25^\circ\text{C}$ )
- US continuous reading on iris, wall and equator
- Treatment divided in two steps



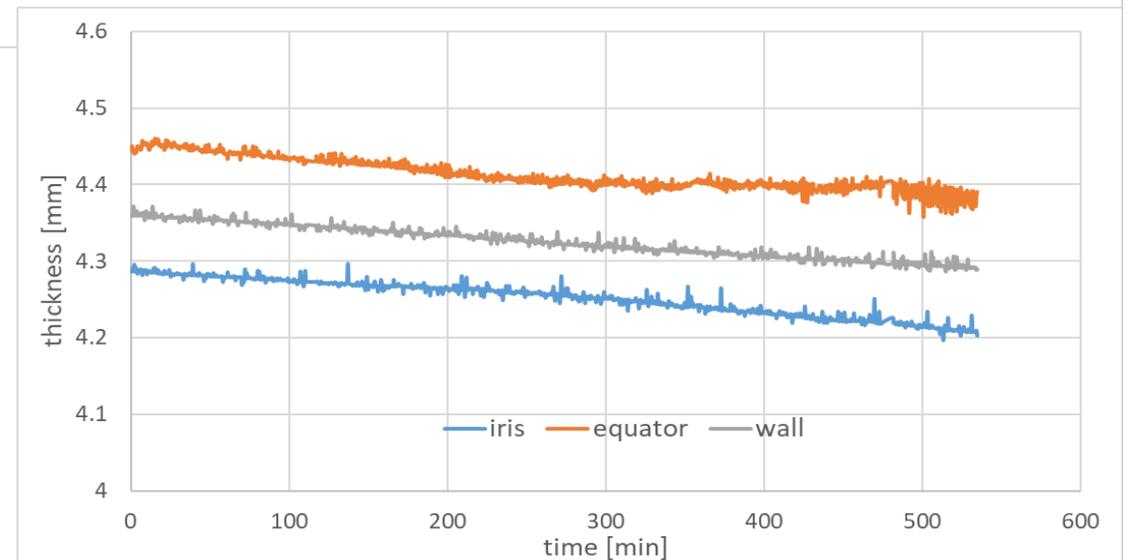
# Bulk EP on-line measurements

Thermocouples on cavity surface, acid inlet and outlet temperature, instantaneous current



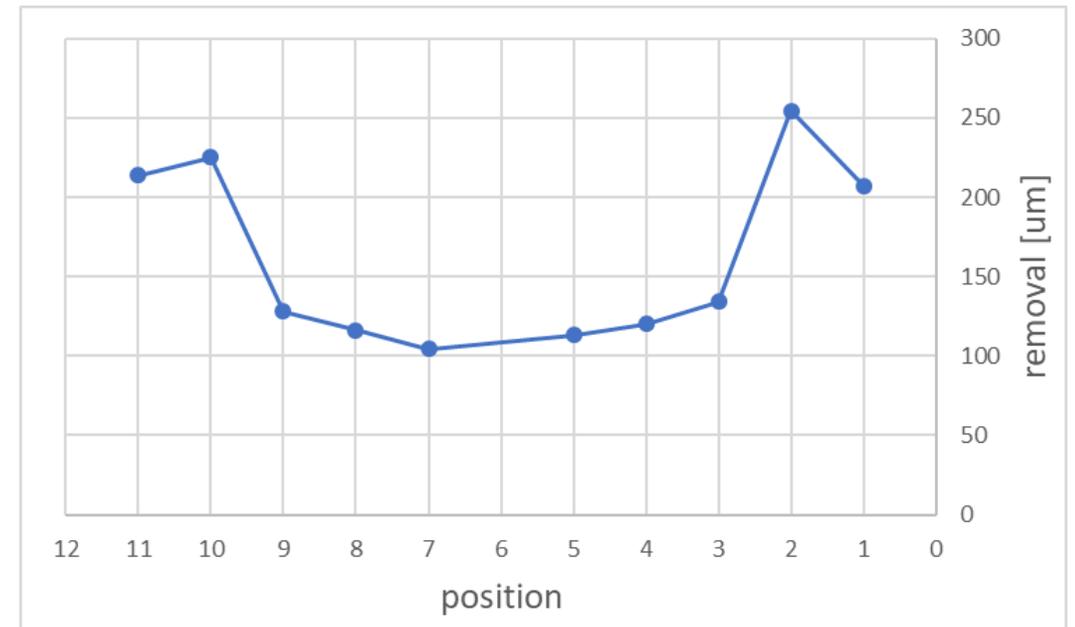
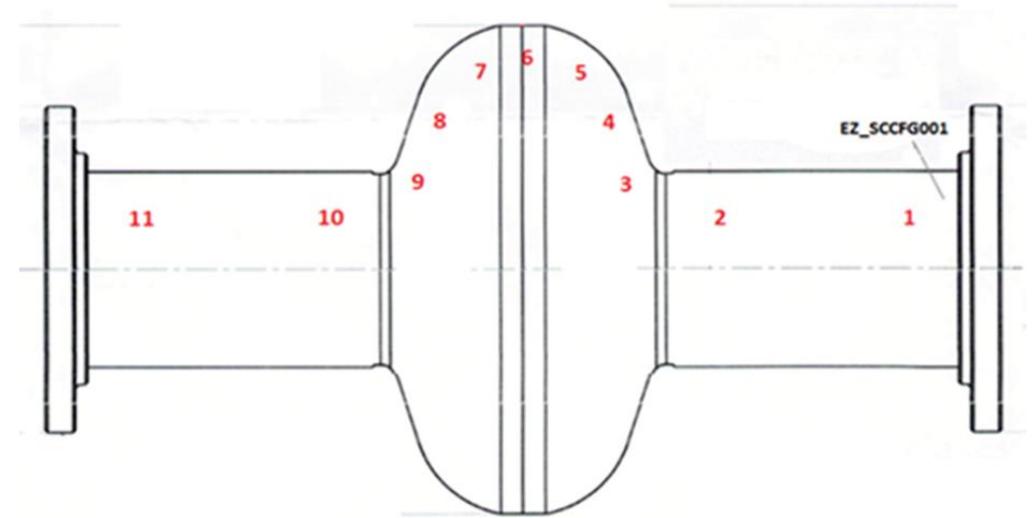
Multi-probe US continuous thickness measurement

step	item	iris	wall	equator
1	rate [ $\mu\text{m min}^{-1}$ ]	0.15	0.13	0.12
	removal [ $\mu\text{m}$ ]	82	71	61
2	rate [ $\mu\text{m min}^{-1}$ ]	0.14	0.12	0.11
	removal [ $\mu\text{m}$ ]	76	70	59



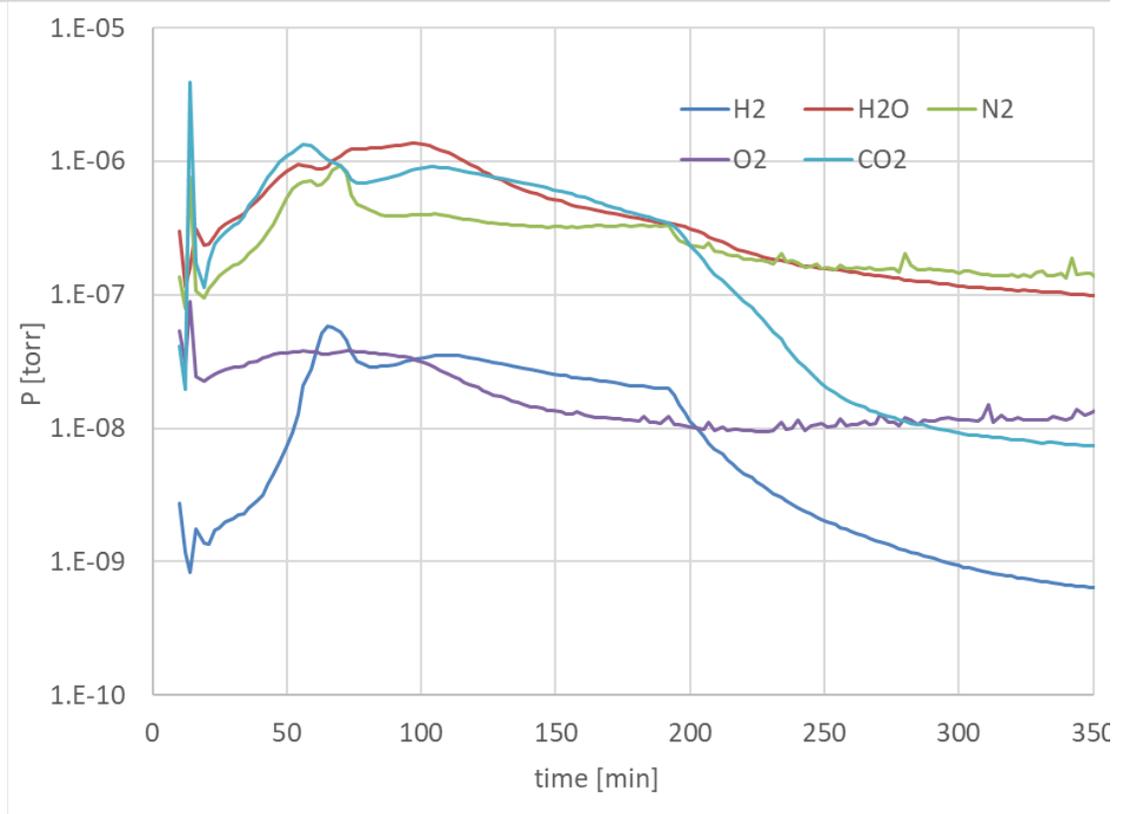
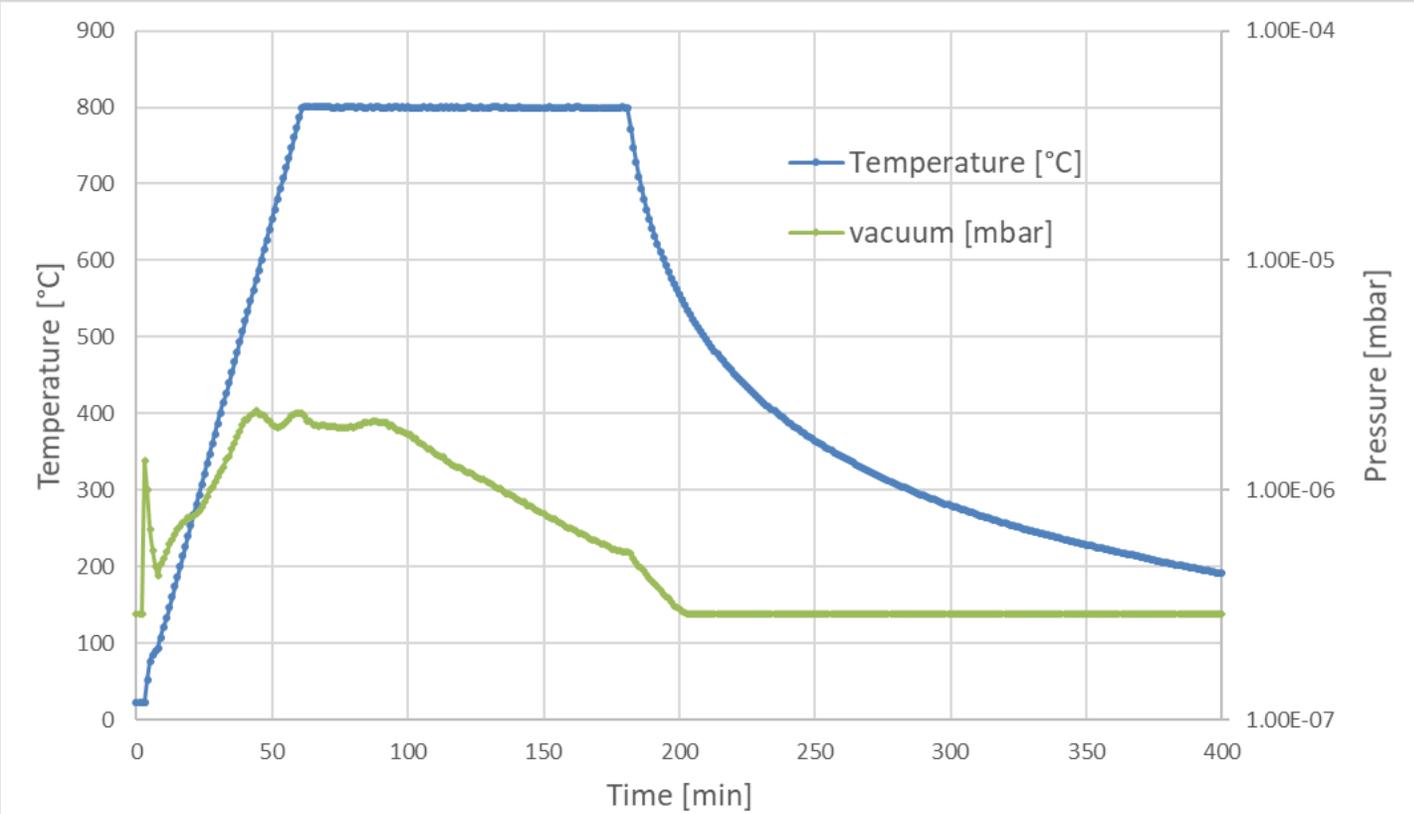
# Offline treatment results

- Treatment duration: 1139 min
- Initial Nb concentration in acid: 4.5 g/L
- Total removal [by weight]: 156.7  $\mu\text{m}$
- Frequency shift: -231.9 kHz
- Calculated sensitivity: -1.48 kHz/ $\mu\text{m}$
- Calculated etching rate [avg.]: 0.14 mm/min
- Calculated iris/equator removal ratio: 1.7
- Final Nb concentration in acid: 7.9 g/L
- Visual inspection
- Replicas and Roughness measurement: after VT so to preserve surface cleanliness
- Lower temperature setpoint:
  - Improved removal uniformity
  - ...but lower removal rate, which has to be compensated by a longer treatment duration



# Heat treatment w and w/o Doping

- Typical thermal cycle: ramp up to 800°C, than stop for 2 h, then ramp down (à la XFEL)
- Doping recipe: 2/6 (2 min. with 25 mTorr Nitrogen pressure, 6 min. 800°C annealing)
- RGA acquisition during temperature ramp and doping procedure
- Cavity flanges covered by Nb foils during doping

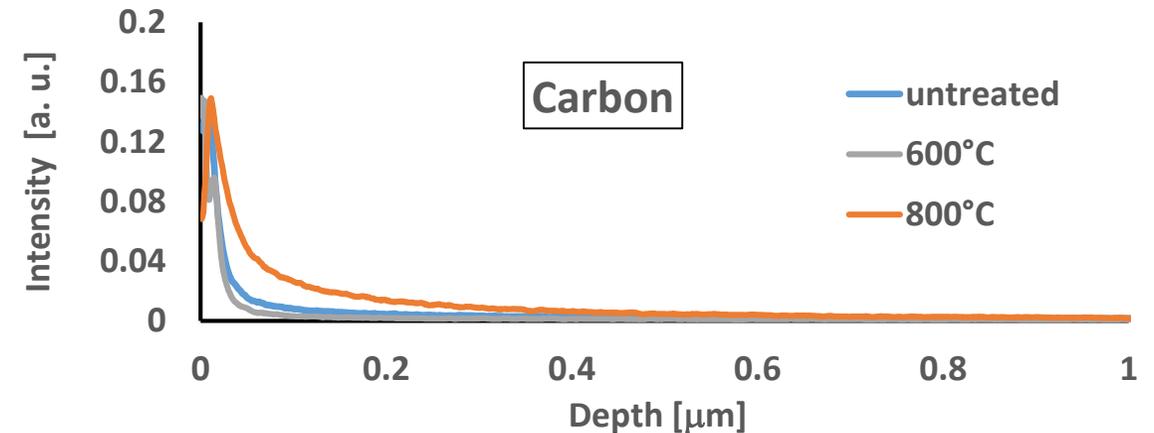
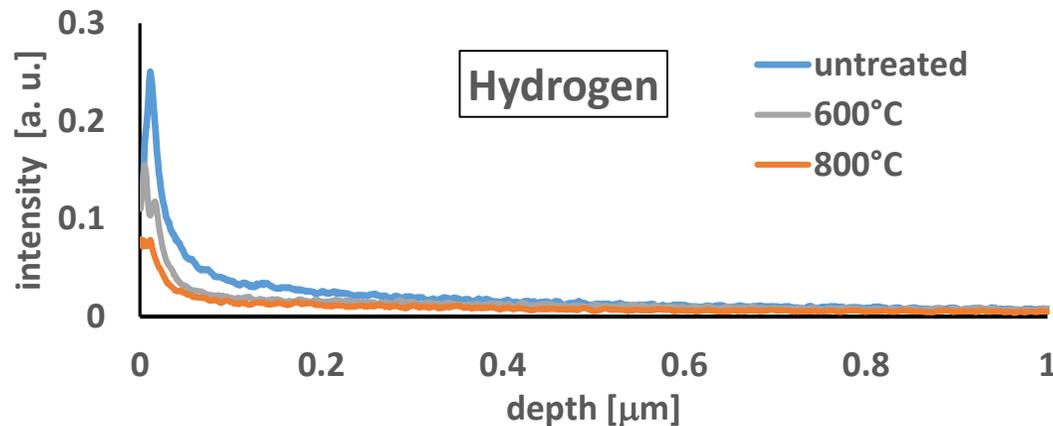


# Furnace qualification with Nb samples

- RRR measurements before and after 800°C  
13% variation is in line with as registered by other furnaces (mainly Oxygen diffusion?)

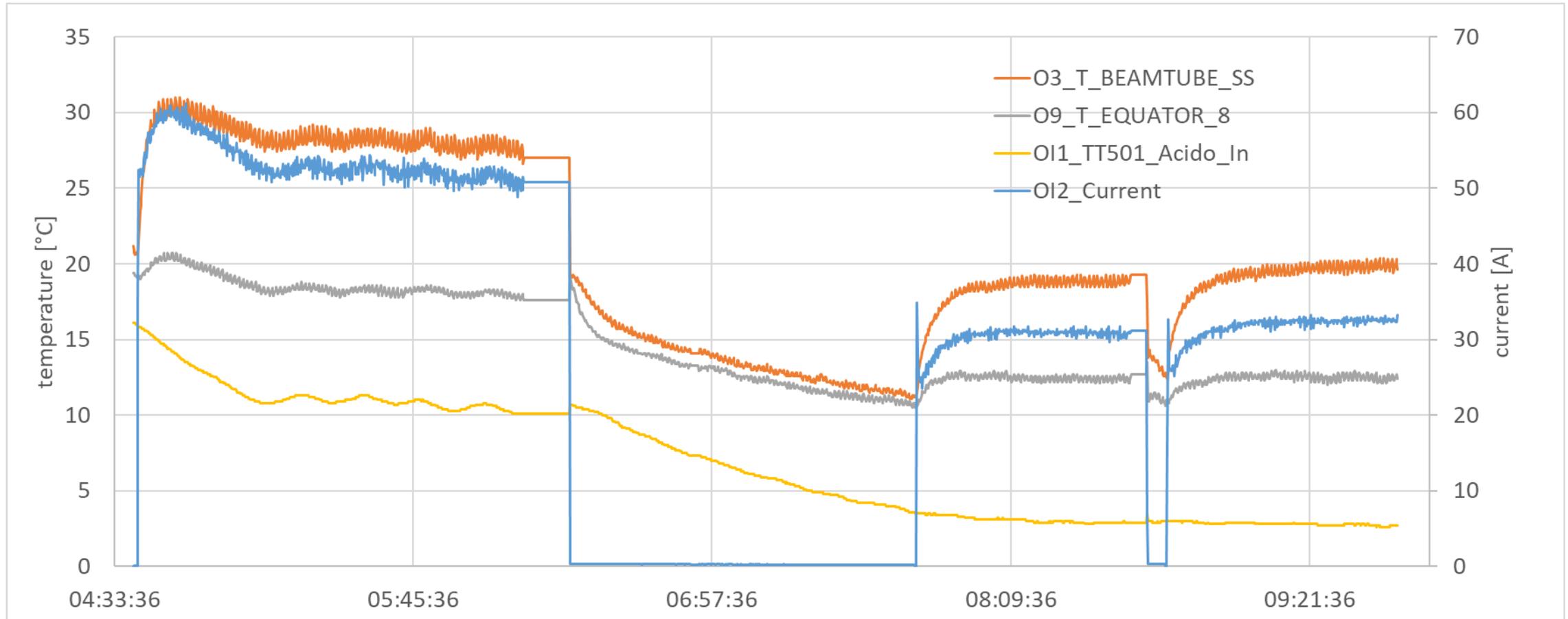
	RRR pre HT	RRR post 800°C HT	Variation (%)
Sample 1	385	383	1
Sample 2	383	335	13

- Depth profiling with GDOES (Glow Discharge Optical Emission Spectroscopy)
  - No relevant variation for O<sub>2</sub>, C, N<sub>2</sub>, S, Mo, Ti, P, Cl
  - H<sub>2</sub> decreases due to high temperature desorption



- SEM-EDX analyses: no significant surface contaminations
- We consider the surface after the 800°C clean and the furnace qualified for the upcoming 800°C treatments with and without N<sub>2</sub> doping

# 25 $\mu\text{m}$ Final «cold» EP



## First 15 $\mu\text{m}$ (300 kC) warm

V=17V, 19-20°C acid chilling setpoint  
Max 25°C on cell, 28°C on beamtubes

## Acid chilling

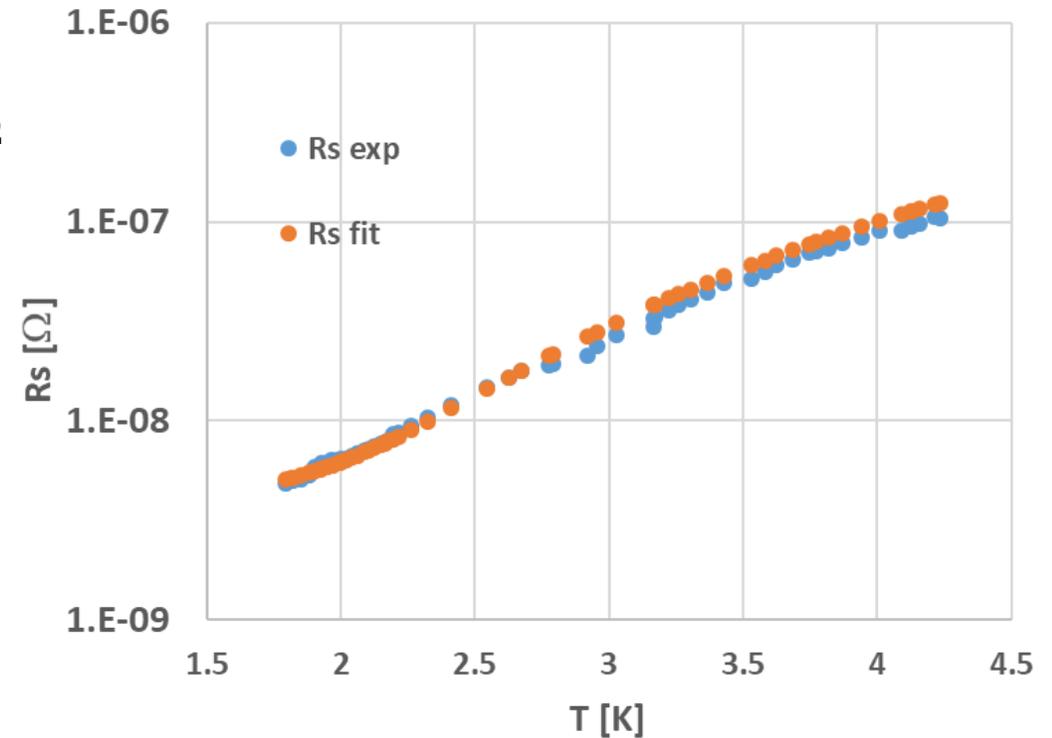
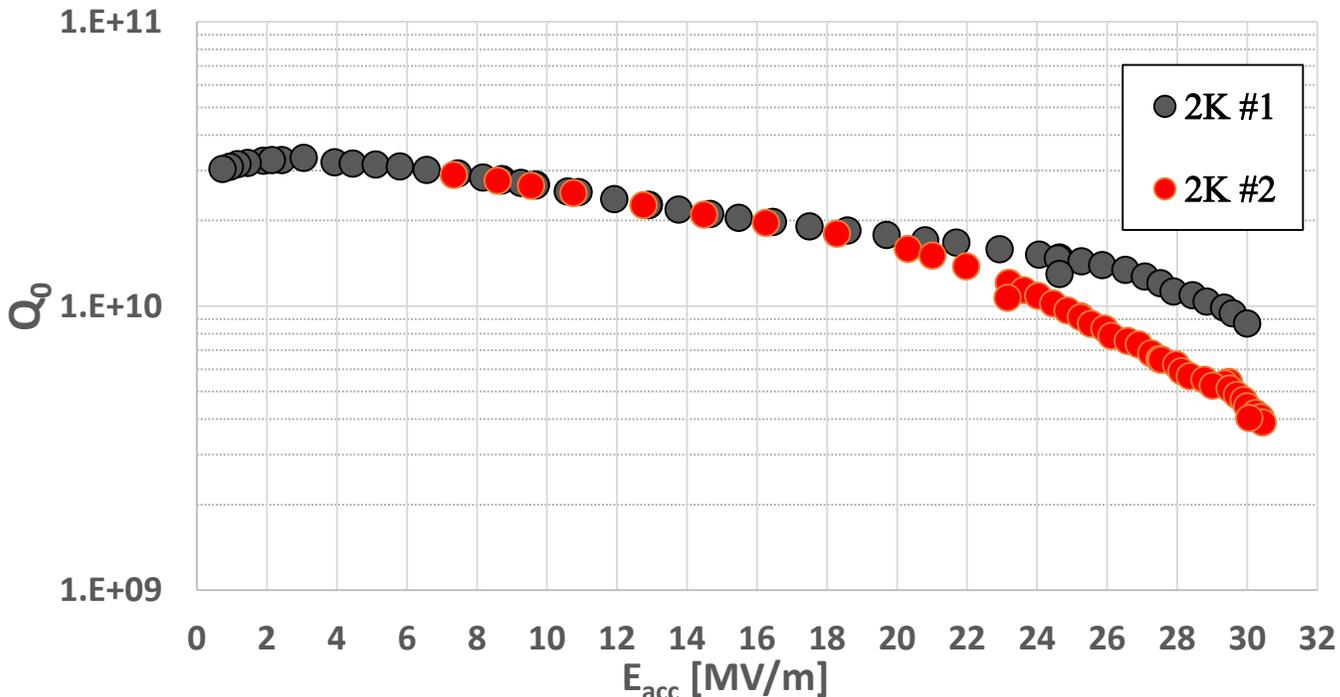
Treatment stopped (V=0).  
Acid cooled down to 7-8°C

## Last 10 $\mu\text{m}$ (200 kC) cold

V=17V, 7-8°C acid chilling setpoint  
Max 13°C on cell, 18°C on beamtubes

# FG001 single cell VT results

- Slow cooldown (0.5K/min) across critical point (9.2K)
- No Helmholtz coils for magnetic field compensation
- 8 mG of residual field at cavity equator
- assuming 0.3 n $\Omega$ /mG for baked niobium at 650 MHz:  $R_0=2.4$  n $\Omega$
- $Q$  @low field= $3.3E10 \rightarrow 5.9$  n $\Omega$  surface resistance
- $Q$  @17 MV/m= $2E10$
- Max field=30.5 MV/M, limited by FE instabilities



Fit results:

- Reduced band gap ( $\Delta/k$ ): 17.4
- Electron mean free path: 26 nm
- Residual resistance: 4.4 n $\Omega$

# What if...

- ....we have Perfect flux expulsion: trapped field residual resistance set to 0
- New  $R_s = 5.9 - 2.4 = 3.5 \text{ n}\Omega \rightarrow Q_0 \text{ @low field} = 5.4 \times 10^{10}$

