ACHIEVEMENT OF 35 MV/m IN THE TESLA SUPERCONDUCTING CAVITIES

USING ELECTROPOLISHING AS A SURFACE TREATMENT

EPAC´04

Lucerne

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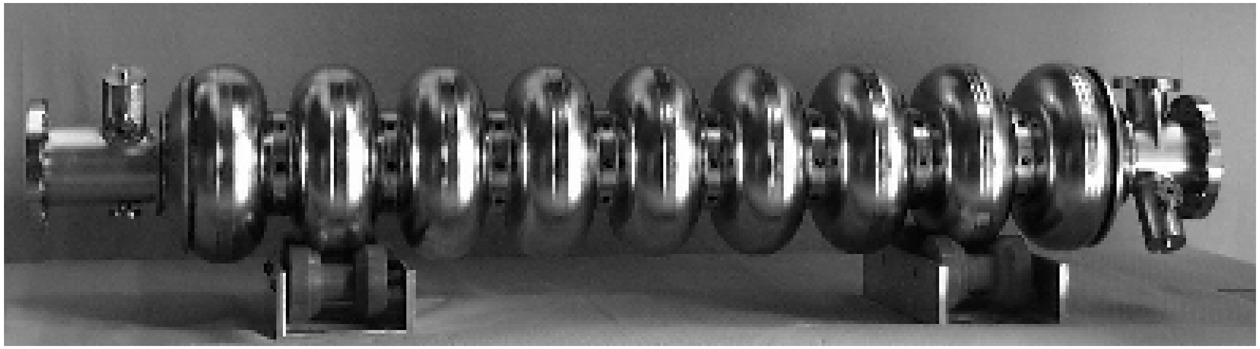
for the TESLA Collaboration

TESLA

TESLA Cavities

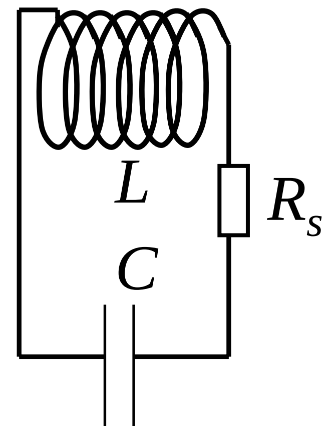


$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

frequency

$$Q_o = \frac{f}{\Delta f} = \frac{G}{R_s}$$

quality factor



Made of solid, pure (RRR >300, high thermal cond.) Niobium

Nb sheets are deep-drawn to make cups (**100 µm tolerances**), which are electron beam welded to form structures.

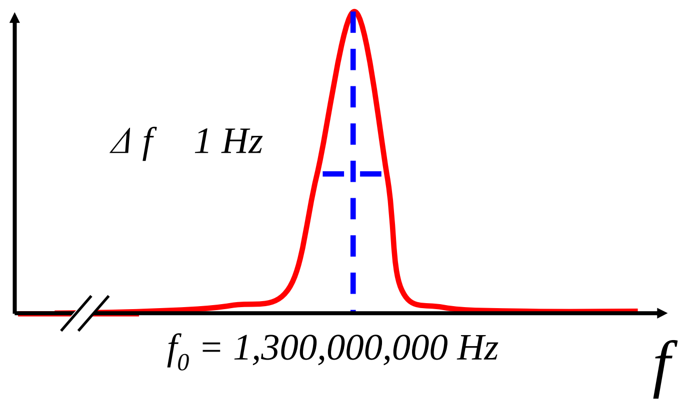
Fill time with coupler 420 µs, i.e. $Q_{ext} = Q_{beam} = 3 \times 10^6$, $\Delta f = 400$ Hz

RF pulse length (400 µs filling + 920 µs flat top) = 1320 µs.

Operated at 2 K in superfluid Helium bath.

RF losses approx. 1 W/m.

RF amplitude and phase adjusted during filling and flat top to compensate beam loading. In steady state **essentially 100% rf input power goes into the beam.**



Natural bandwith

$Q_0 \sim 10^9$ -10^{10}

TESLA Challenges

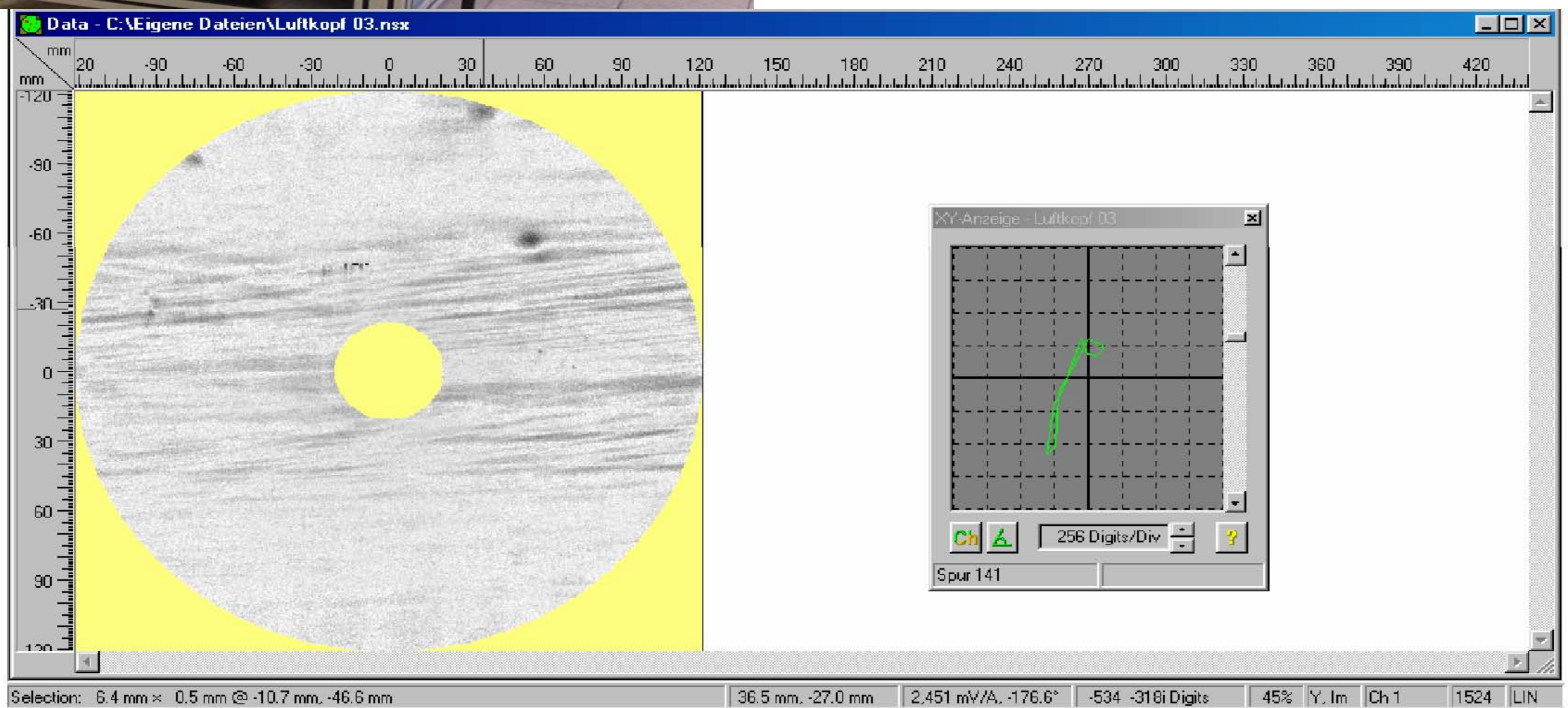
- Gradient
  - For superconducting (SC) cavities
    - 1990: 5 MV/m in operating accelerators
    - 1990: First TESLA Workshop in Cornell
    - 1994: 1.3 GHz five-cell cavity achieves 25 MV/m in Cornell
    - 2000: 25 MV/m achieved routinely in nine-cell cavities at TTF
    - 2001: TESLA Technical Design Report: 800 GeV option
    - 2003: 35 MV/m achieved in several multi-cells
- Auxiliaries
  - e.g. Active Tuner

Superconducting Cavity Technology

- the small surface resistance of the superconducting necessitates avoidance of NC contaminations larger than a few μm
  - NC contaminants lead to increased power dissipation and thermal breakdown (quench)
  - as opposed to SC magnets the stored energy this is **not** a critical problem: energy in the cavities is in the order of a Joule
  - as opposed to NC structures there is **no damage** associated to thermal breakdown
- therefore
  - detailed material specification and quality control are done
    - e.g. sufficiently high thermal conductivity of the niobium
  - tight specification for fabrication e.g. welds have been implemented
  - clean room technology is a must
- all this is readily available today

Eddy Current Scanner for Niobium Sheets

Real and imaginary part of conductivity at defect, typical Fe signal



Global view, rolling marks and defect areas can be seen

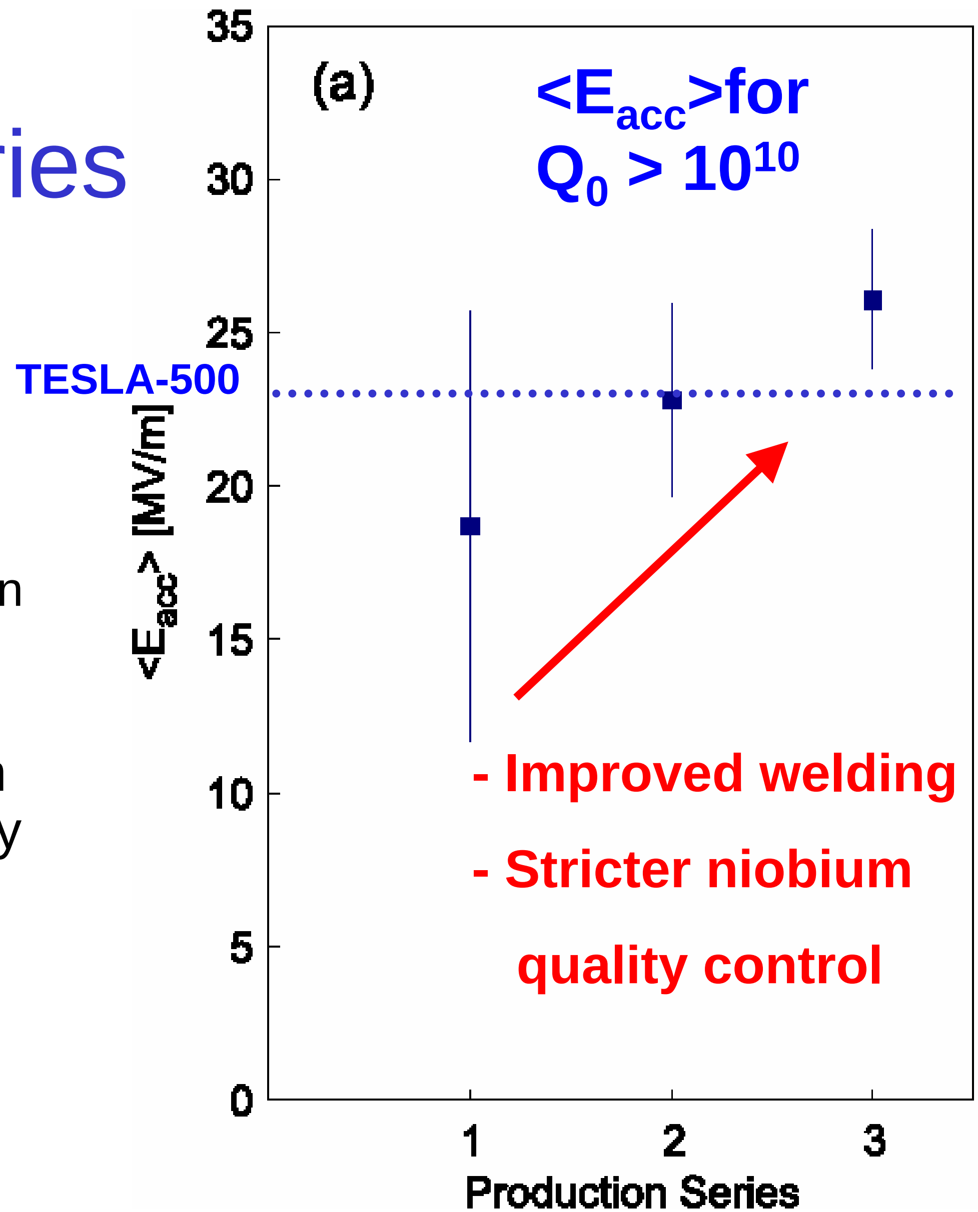
Preparation of TESLA Cavities

Preparation of TESLA Cavities

- High purity niobium sheets of Residual Resistivity Ratio RRR=300 are scanned by eddy-currents to exclude foreign material inclusions like tantalum and iron
- Industrial production of full nine-cell cavities:
  - Deep-drawing of subunits (half-cells, etc.) from niobium sheets
  - Chemical preparation for welding, cleanroom preparation
  - Electron-beam welding according to detailed specification
- 800 °C stress annealing of the full cavity removes hydrogen from the Nb
- Option: 1400 °C high temperature heat treatment with titanium getter layer to increase the thermal conductivity (RRR=500) further
- Cleanroom handling:
  - Chemical etching (or electropolishing) to remove damage layer and titanium getter layer
  - High pressure water rinsing as final treatment to avoid particle contamination

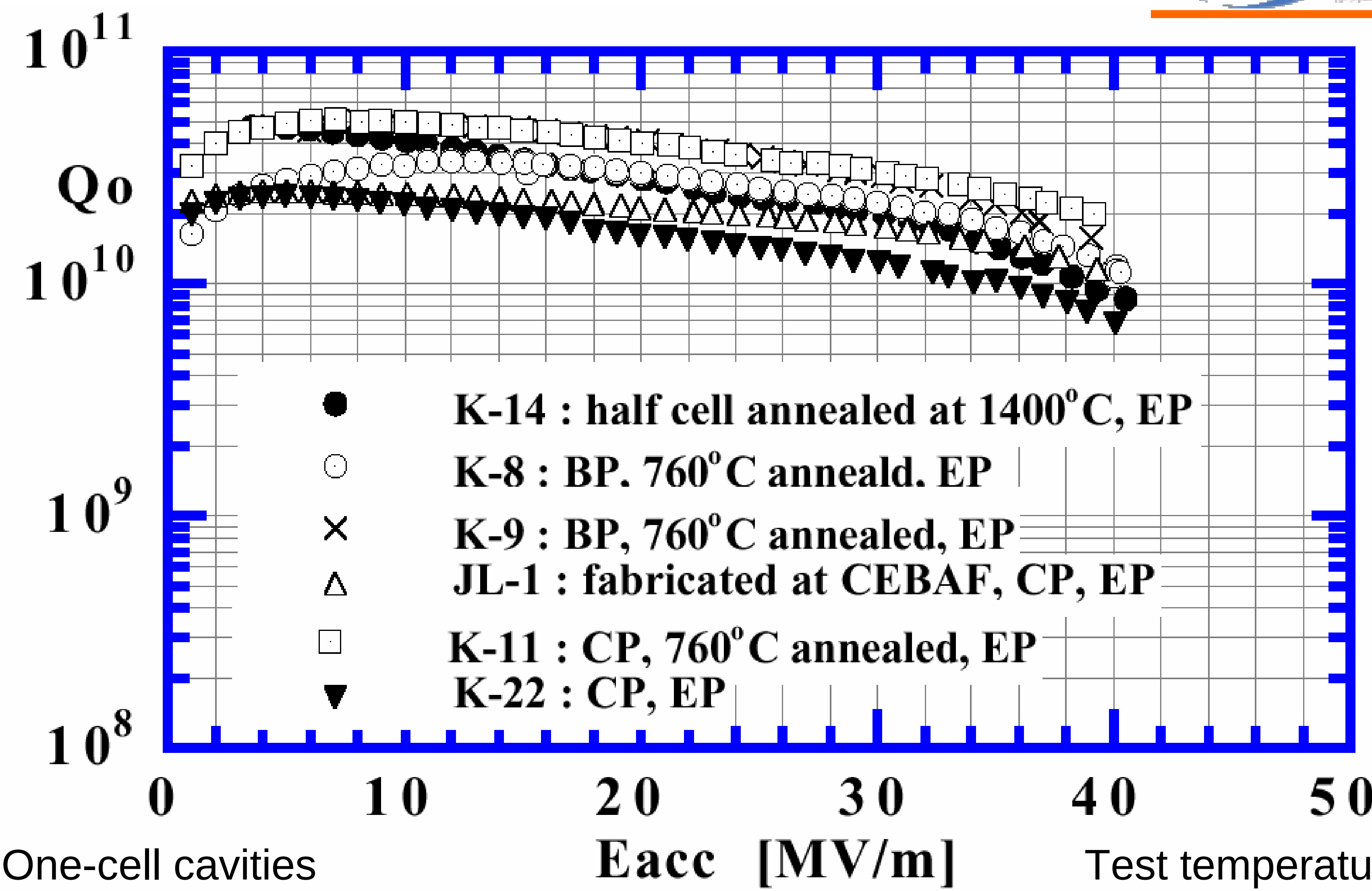
Results of TTF Cavity Production Series

- Cavity shape is optimal (no change since 10 years)
- Three production series of cavities were tested to:
  - qualify companies for cavity production
  - improve performance by precise specification
- Gradient has increased to 25 MV/m in the 3rd production series of cavities by 2001 (TESLA-500 specification)
- At the same time the spread of the performance became smaller
- For TESLA-800 an improved surface treatment became available: Electropolishing (EP)



Electropolished Niobium Cavities

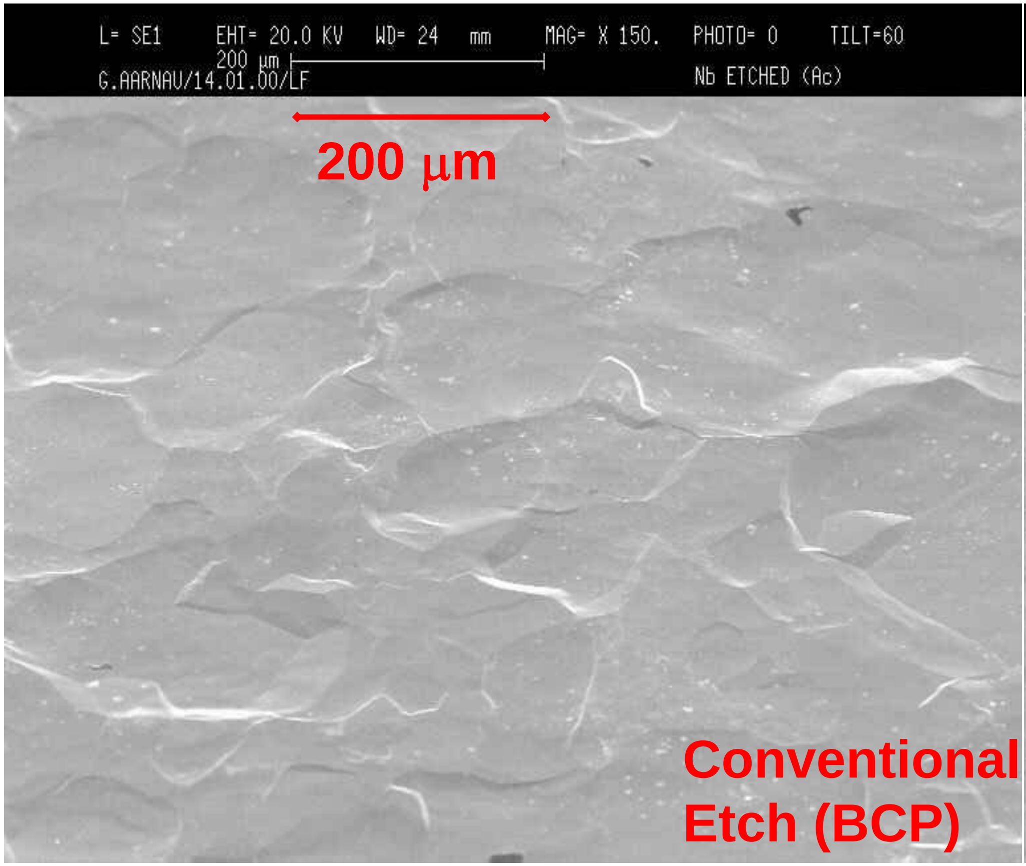
K. Saito et al. KEK 1998/1999

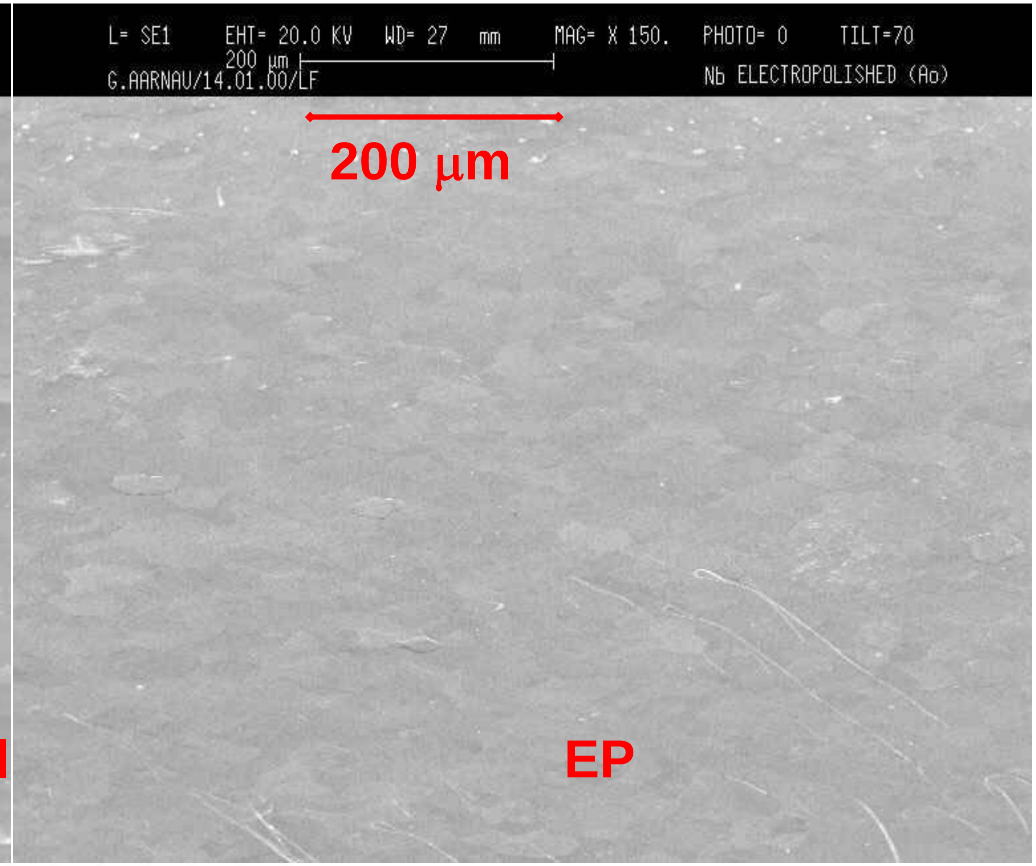


One-cell cavities

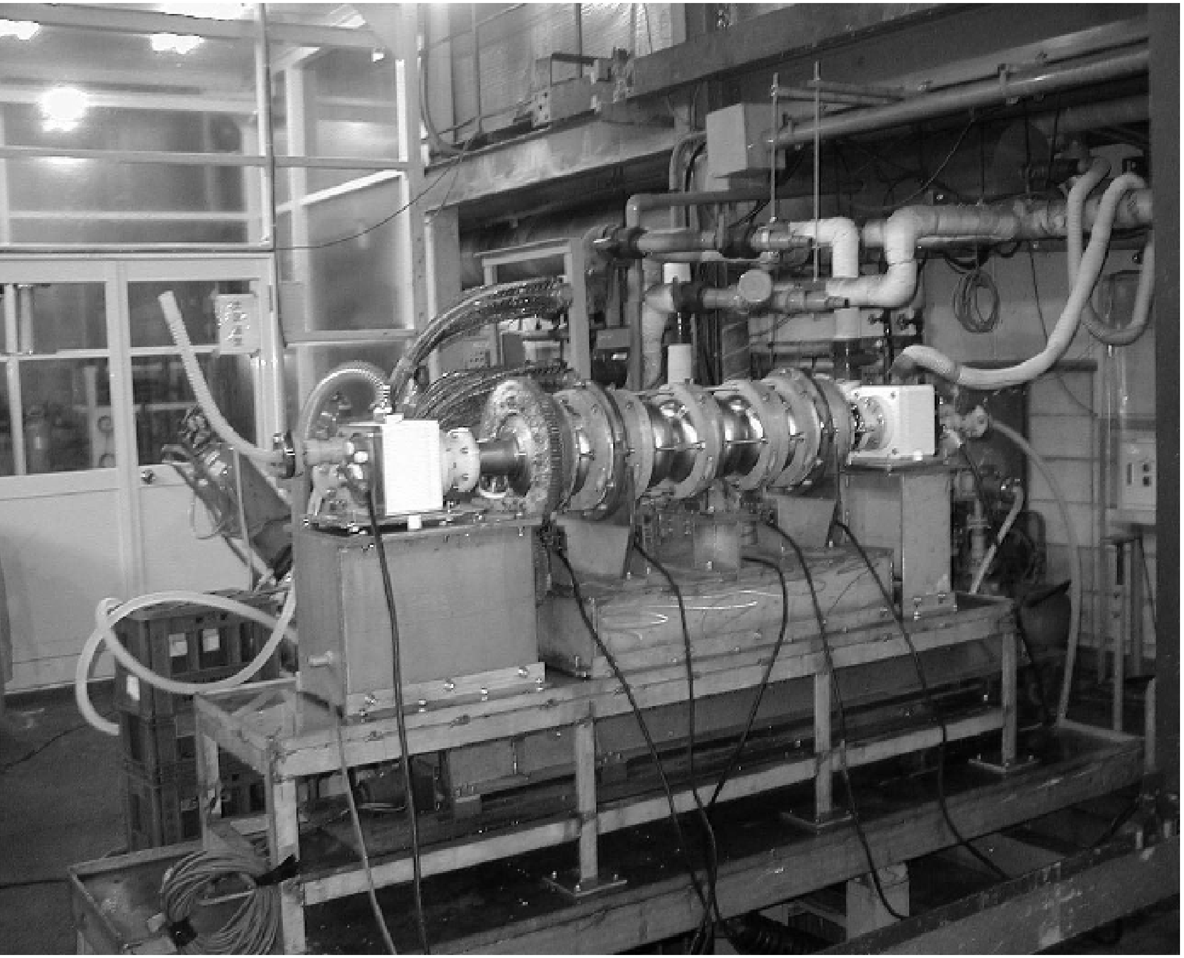
Test temperature: 1.6 K

Electropolishing Offers Improved Surface Quality



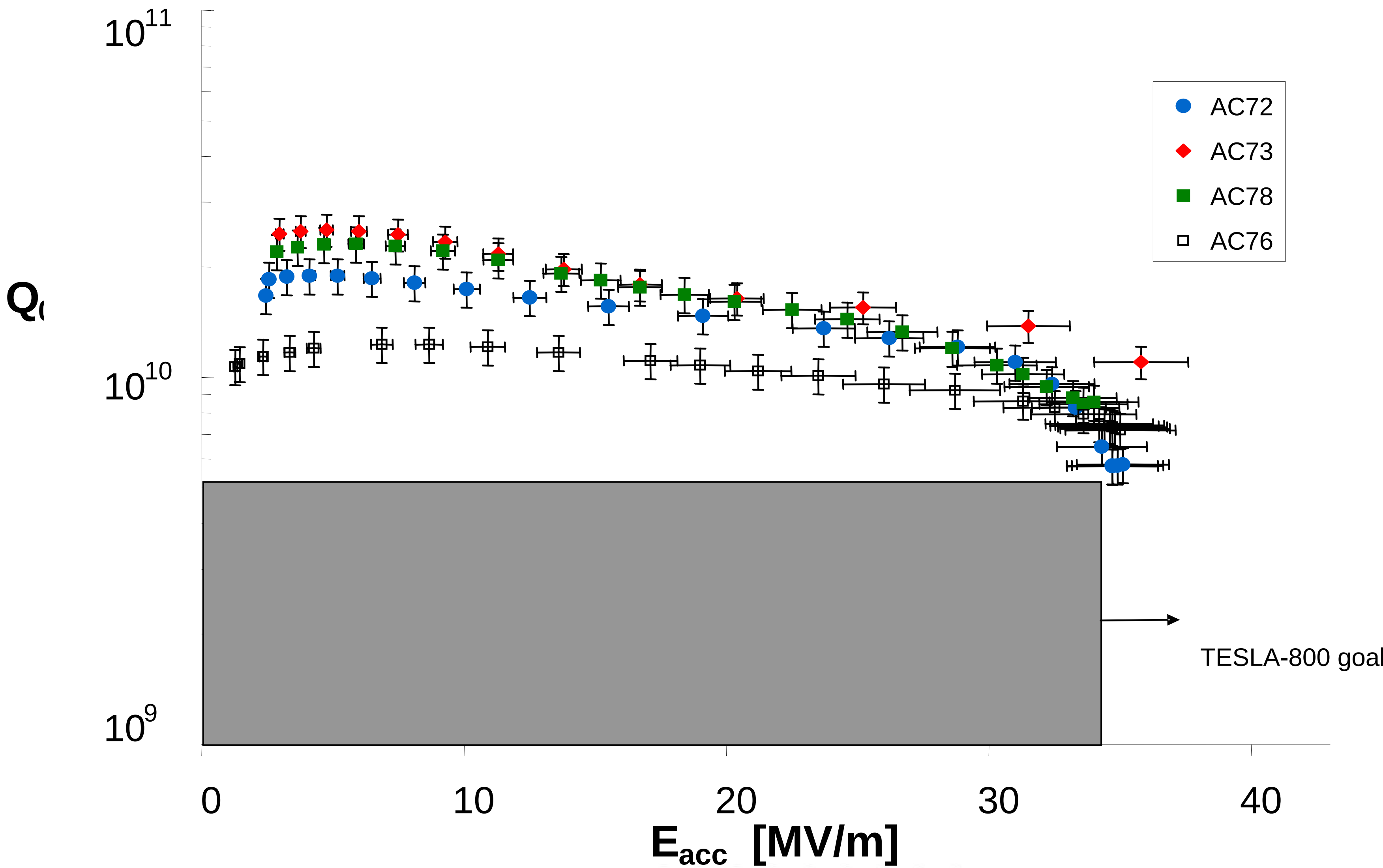


KEK-DESY Collaboration on Electropolishing TESLA Cavities

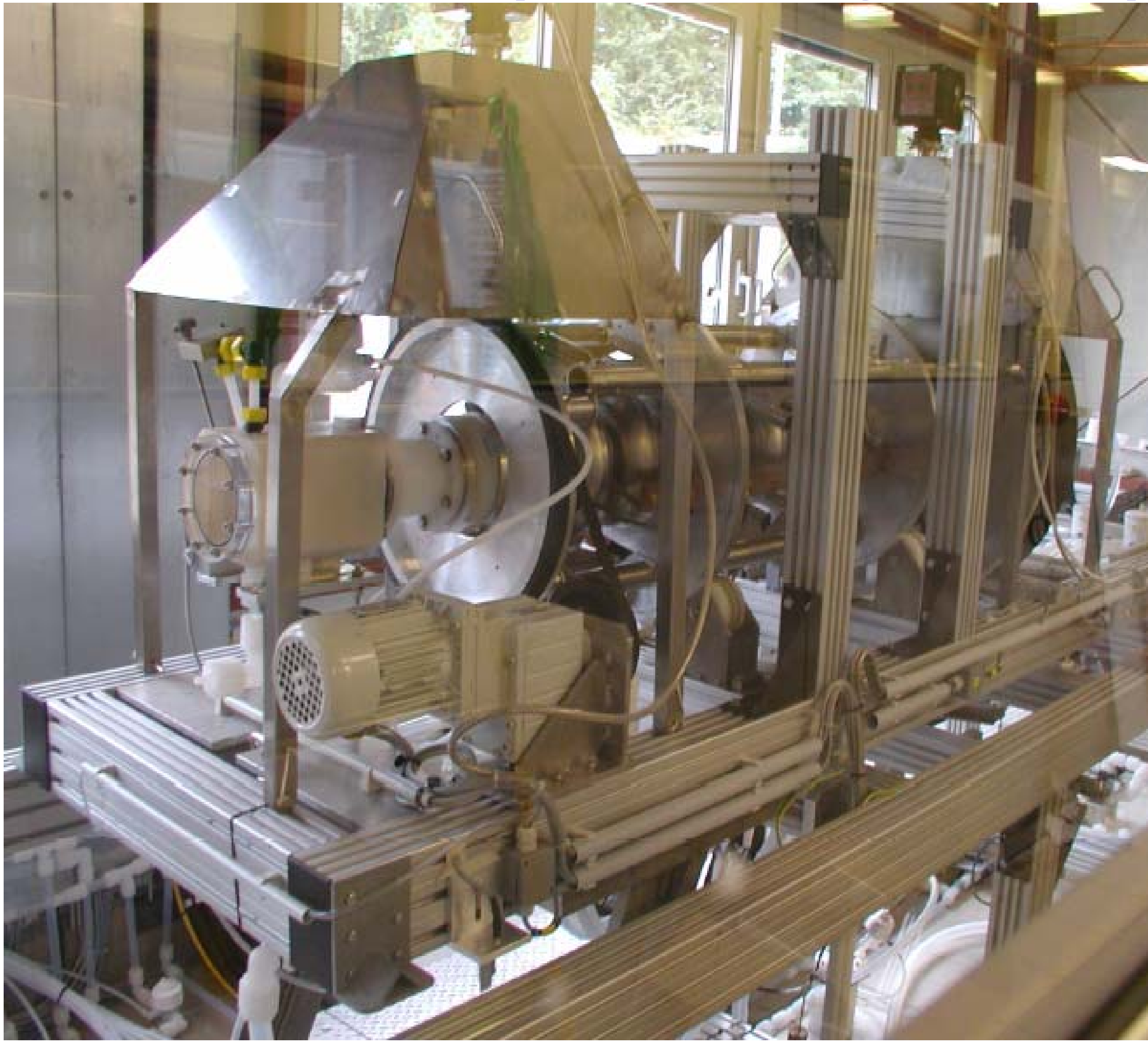


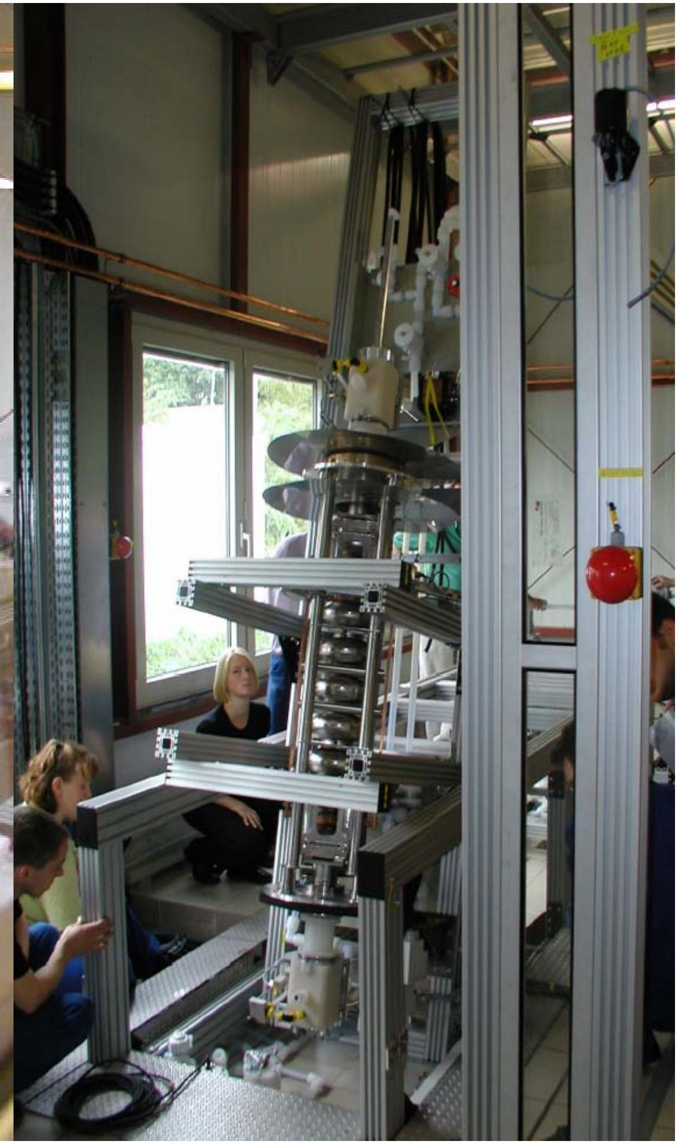
- KEK and the company Nomura Plating have long experience with electropolishing (EP): e.g. Tristan cavities
- Nine-cells provided by DESY
- KEK and Nomura Plating performed the electropolishing process
- Final cleaning done at DESY

KEK-DESY Results on several EP Cavities

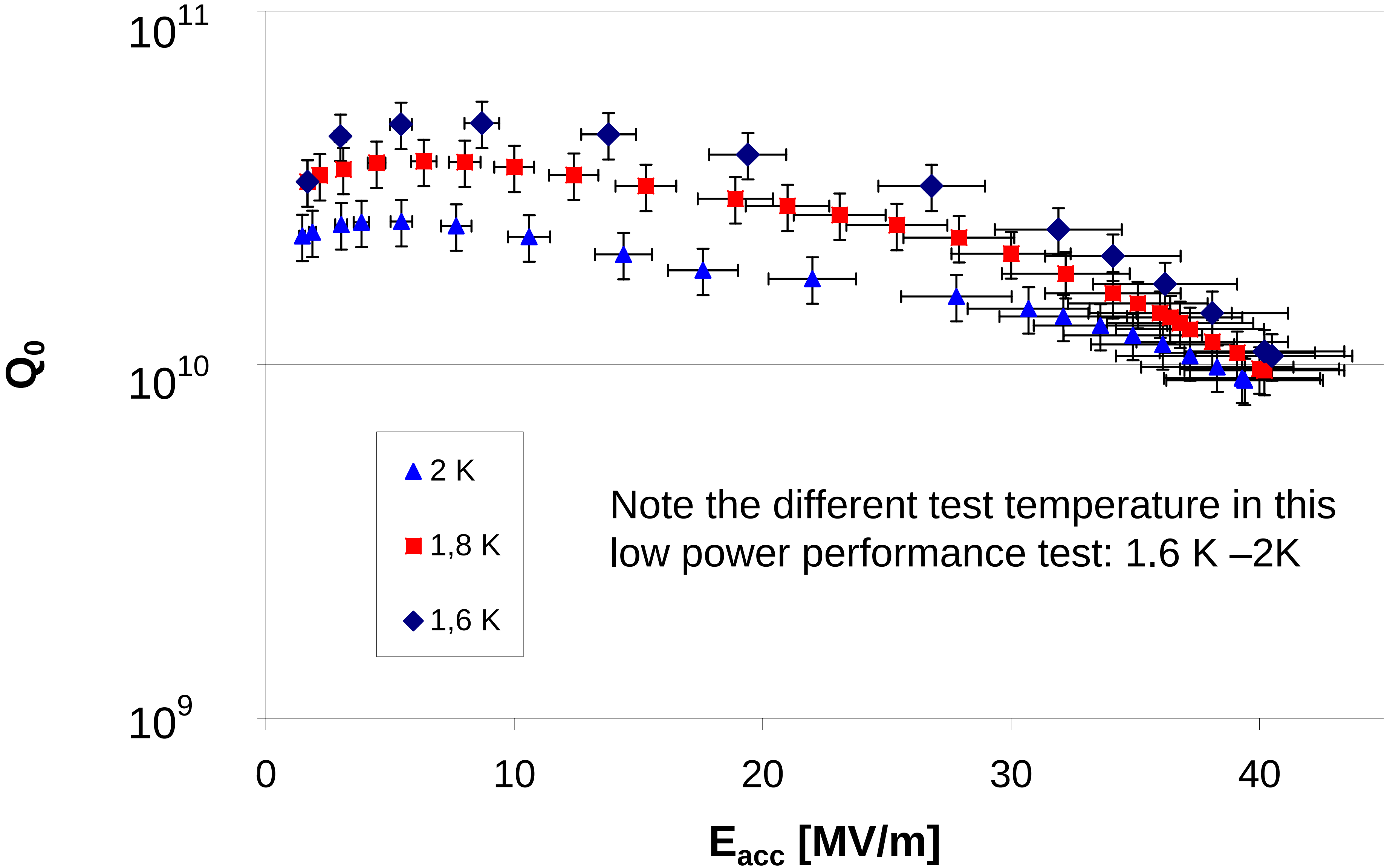


Electropolishing Setup at DESY

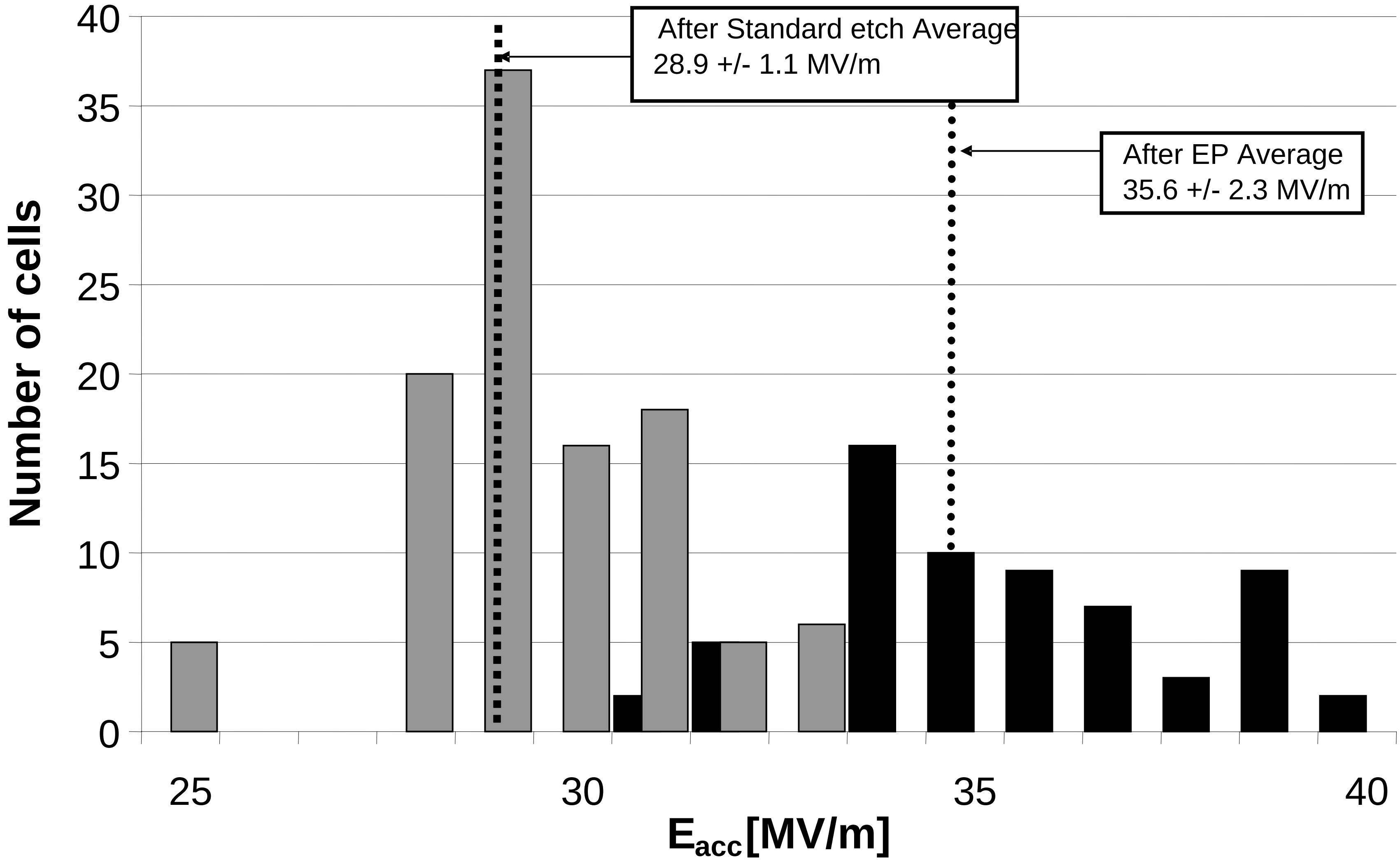




AC70: EP at DESY



Comparison of EP to Standard Etch



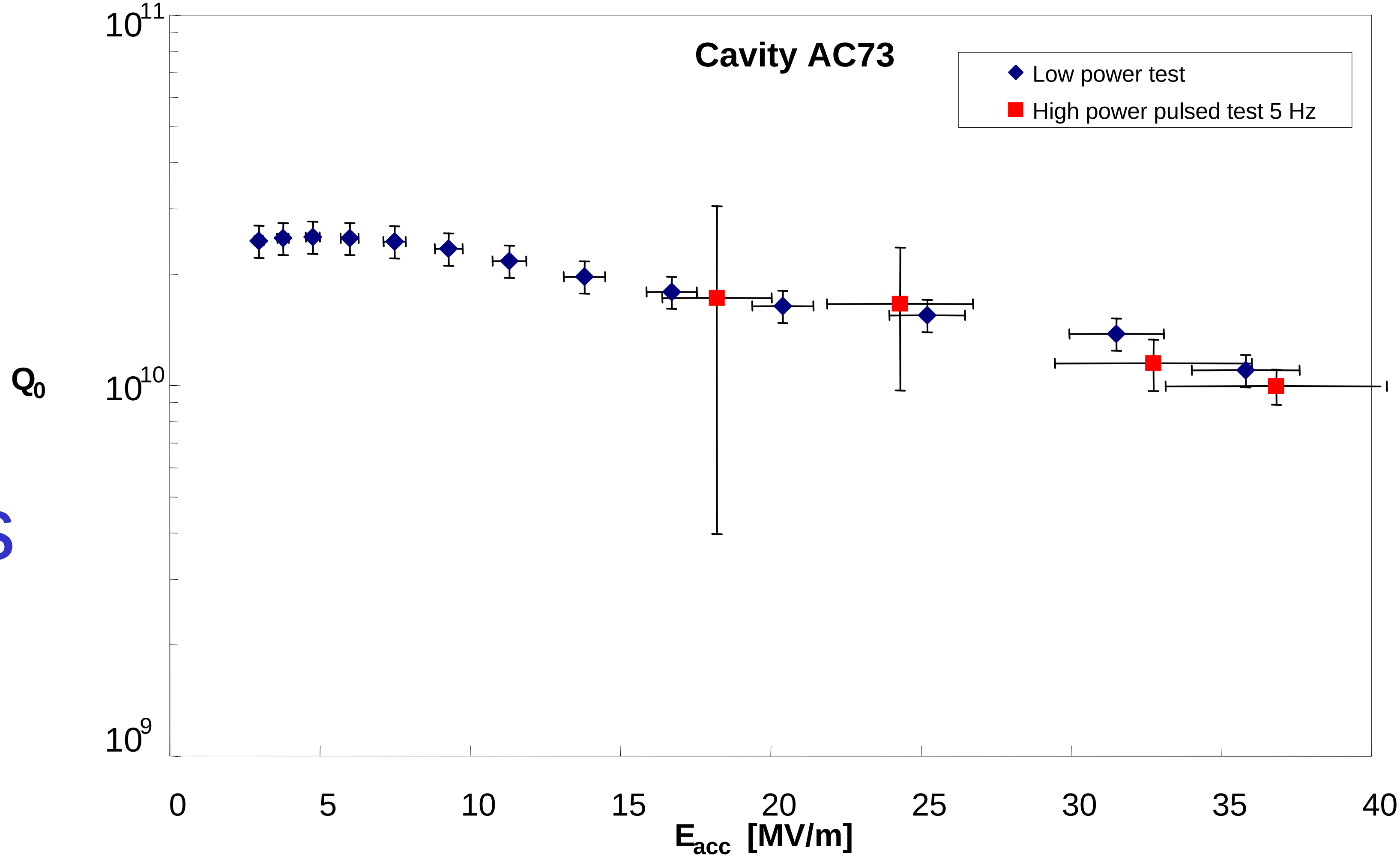
- EP offers systematically higher gradient than standard etch (single cell results from mode analysis of multi-cells)

High-Power Test of Three EP Cavities in the TTF Horizontal Cryostat (CHECHIA)

High Power Test Results

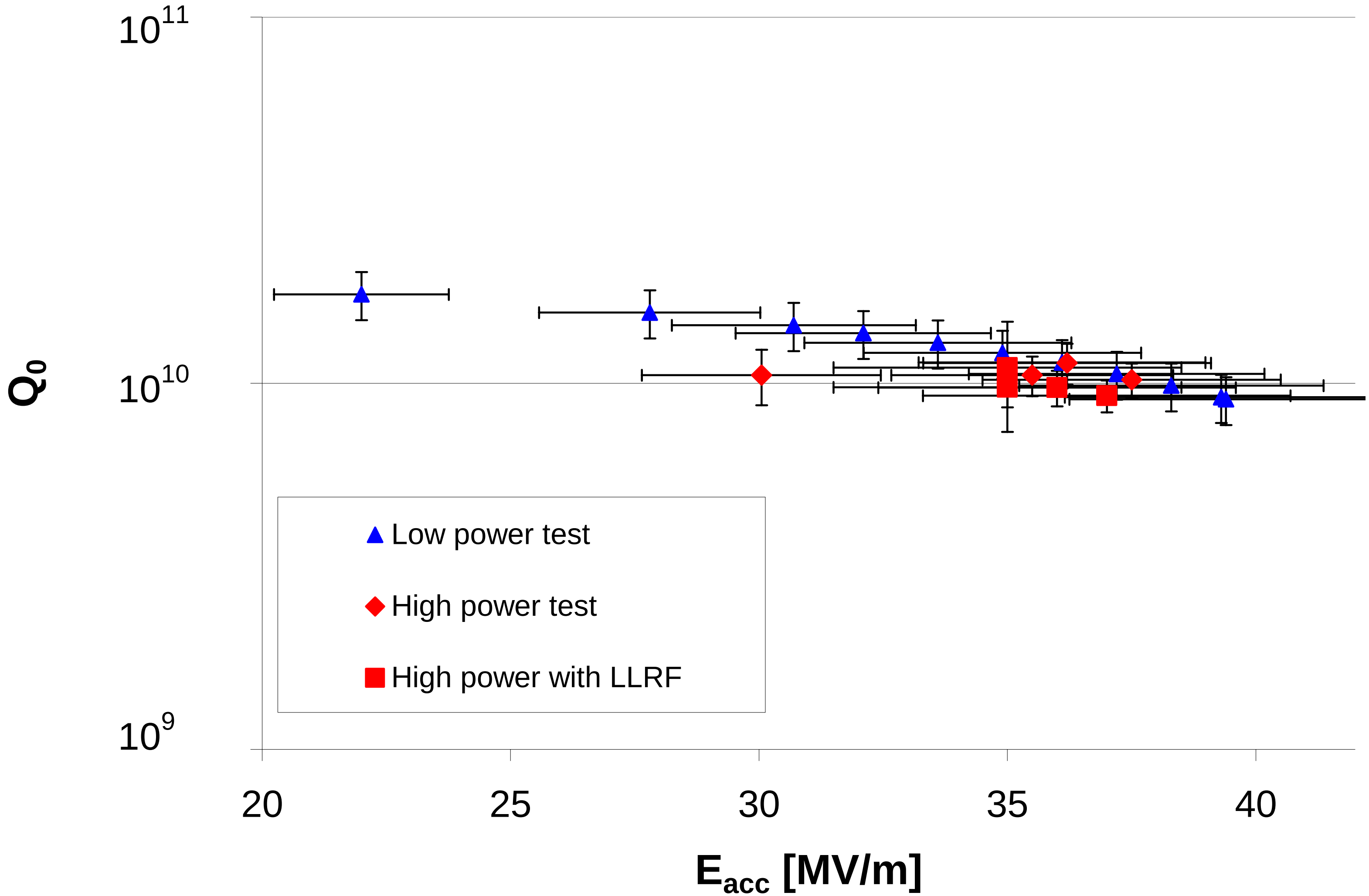
– High power tests give Cavity-Coupler-wise the full information about the system's behaviour e.g. it corresponds to 1/8th of an accelerator module

– Longterm test:
  - No breakdown in 1100 hours at 35 MV/m (neither the Cavity nor the Coupler)
  - No degradation was observed when breakdowns were forced (thermal quenches and coupler breakdowns)

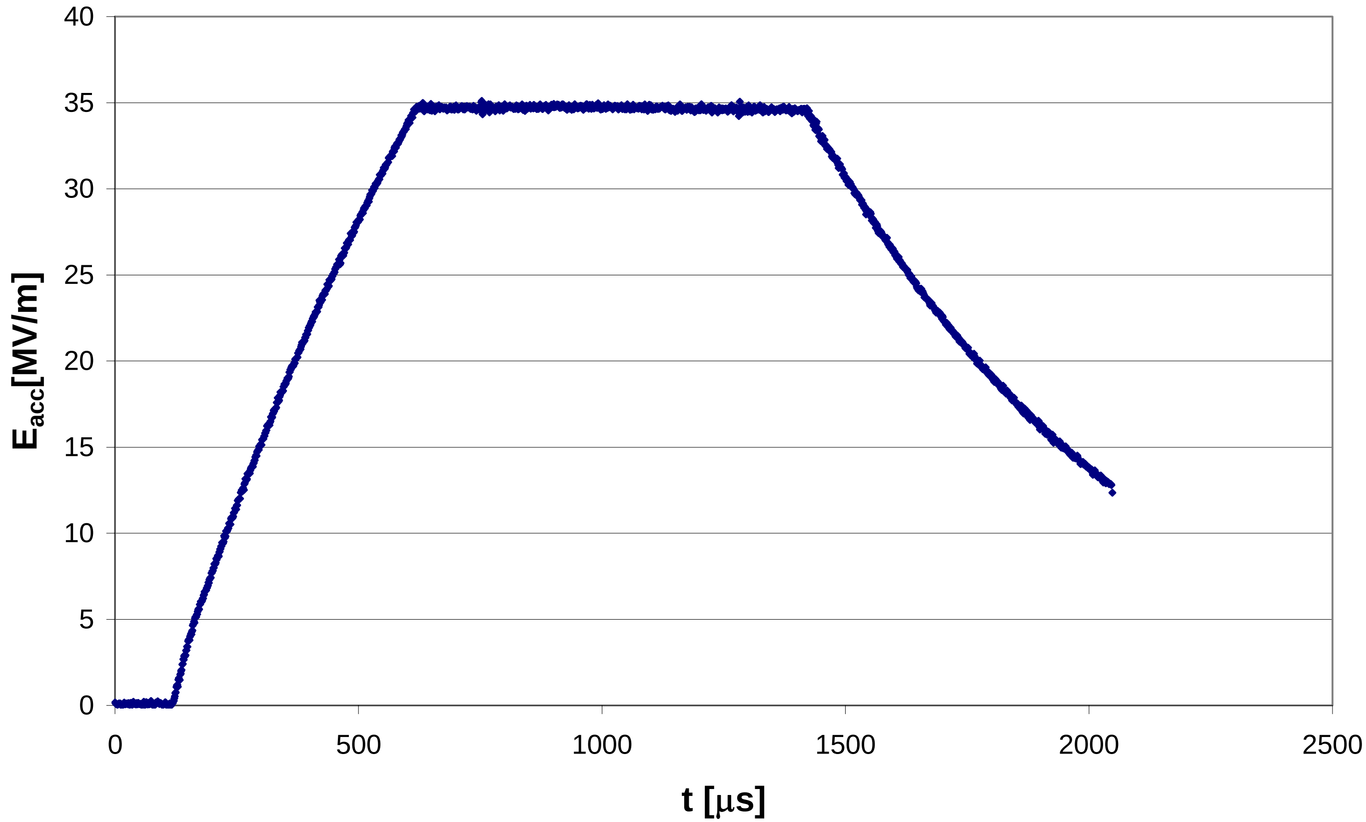


High Power Test Results

- One cavity without post-purification achieved a gradient of more than 35 MV/m with a Q_0 of 10^{10}. This a about a factor of 2 above the TESLA specification.

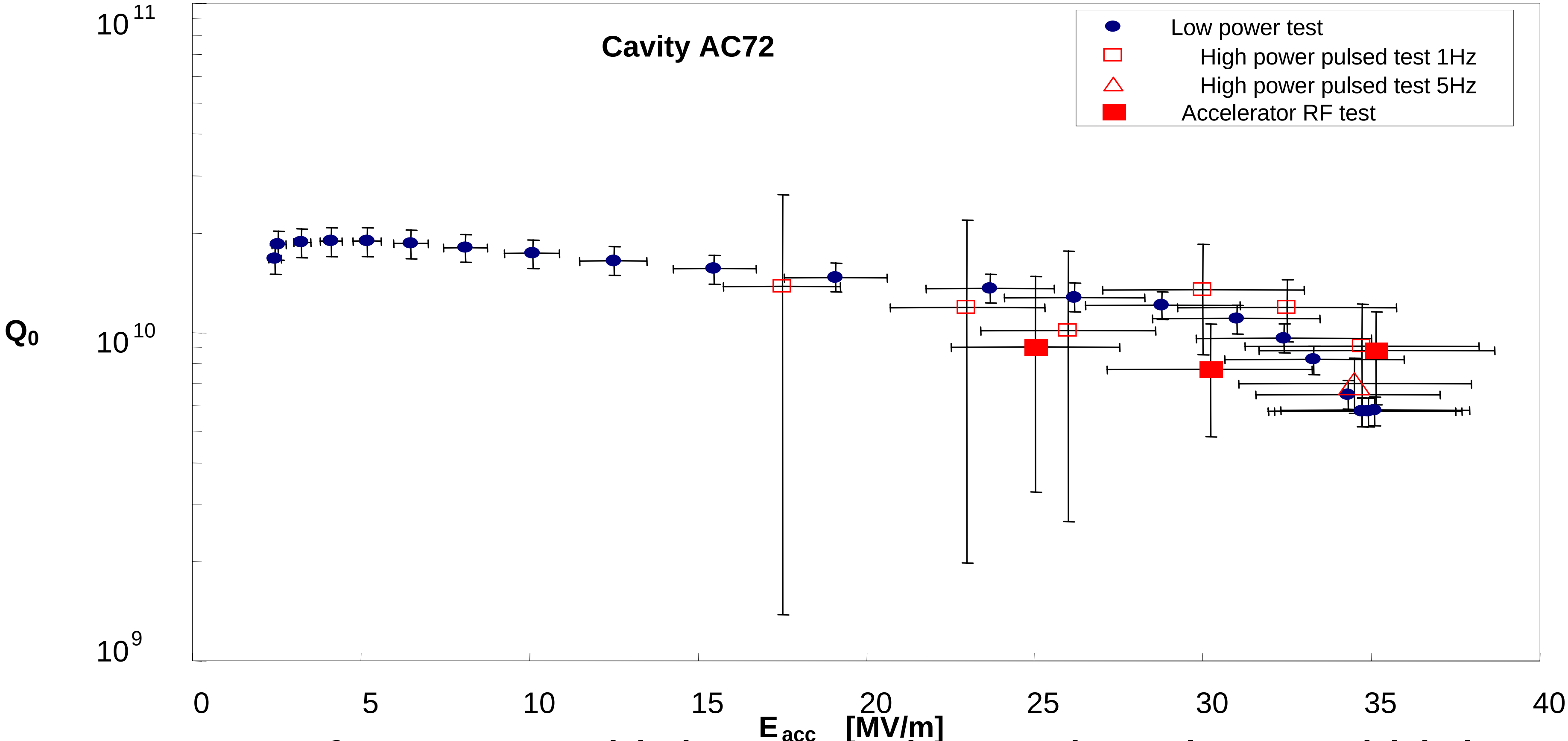


Cavity Test Inside a Module



- One of the electropolished cavities (AC72) was installed into an accelerating module for the VUV-FEL
- Cavity was individually tested in the accelerator with high power RF and beam (i.e. crosscheck of the RF measurement)
- Result: **35 MV/m** in the accelerator!

Cavity Test Inside a Module (ctd.)



- Same performance with beam as in previous low and high power tests without beam
- Very low cryogenic losses as in high power tests
- Standard X-ray radiation measurement indicates no radiation up to 35 MV/m

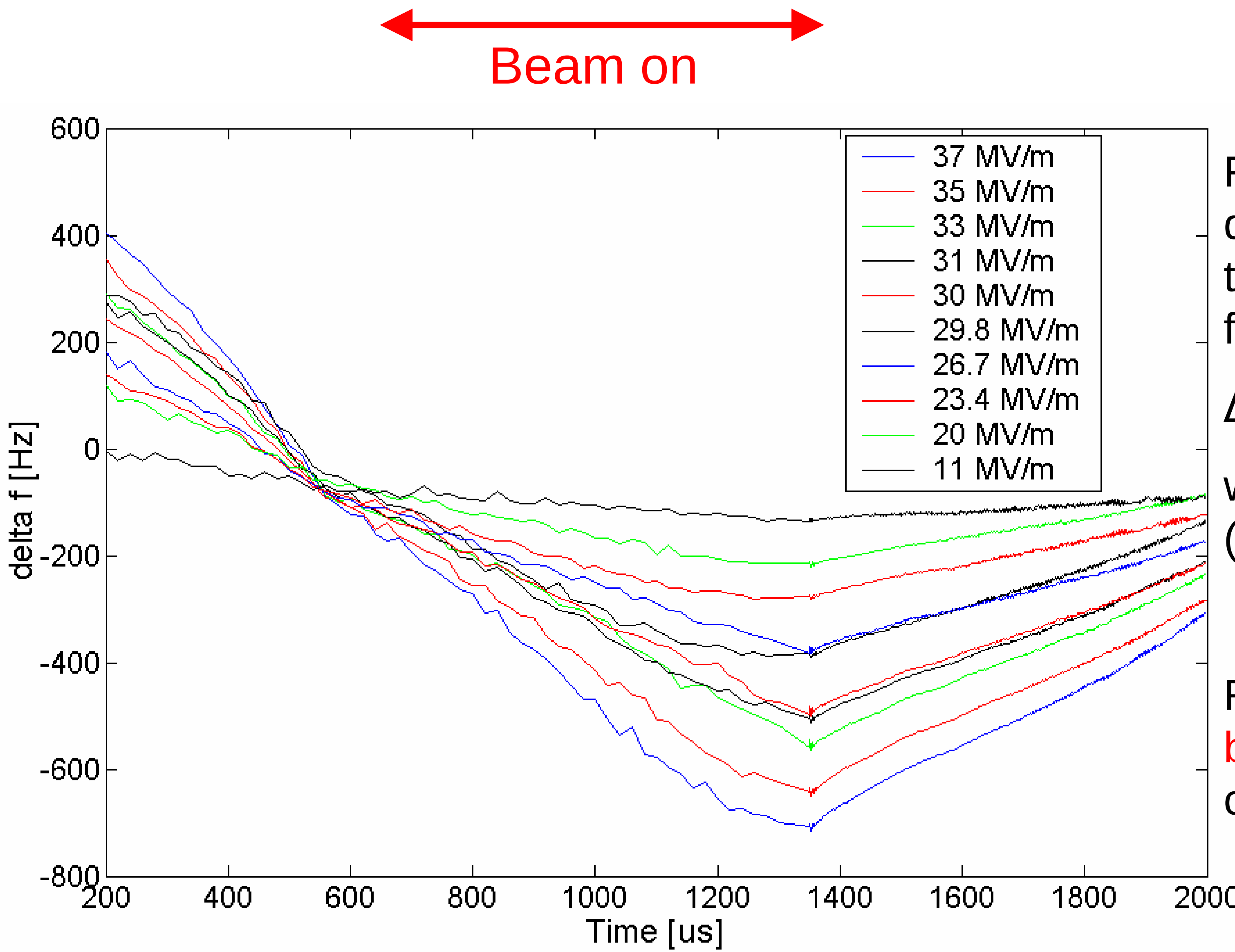
Active Tuner

- Lorentz force detunes the cavity during one RF pulse: If detuning is too large extra RF power would be needed

- Actively compensate the detuning of the cavity during the RF pulse by mechanical means

- Piezoelectric elements are suitable for this application (heavily used for fuel injection in car industry)

Frequency Detuning during RF Pulse



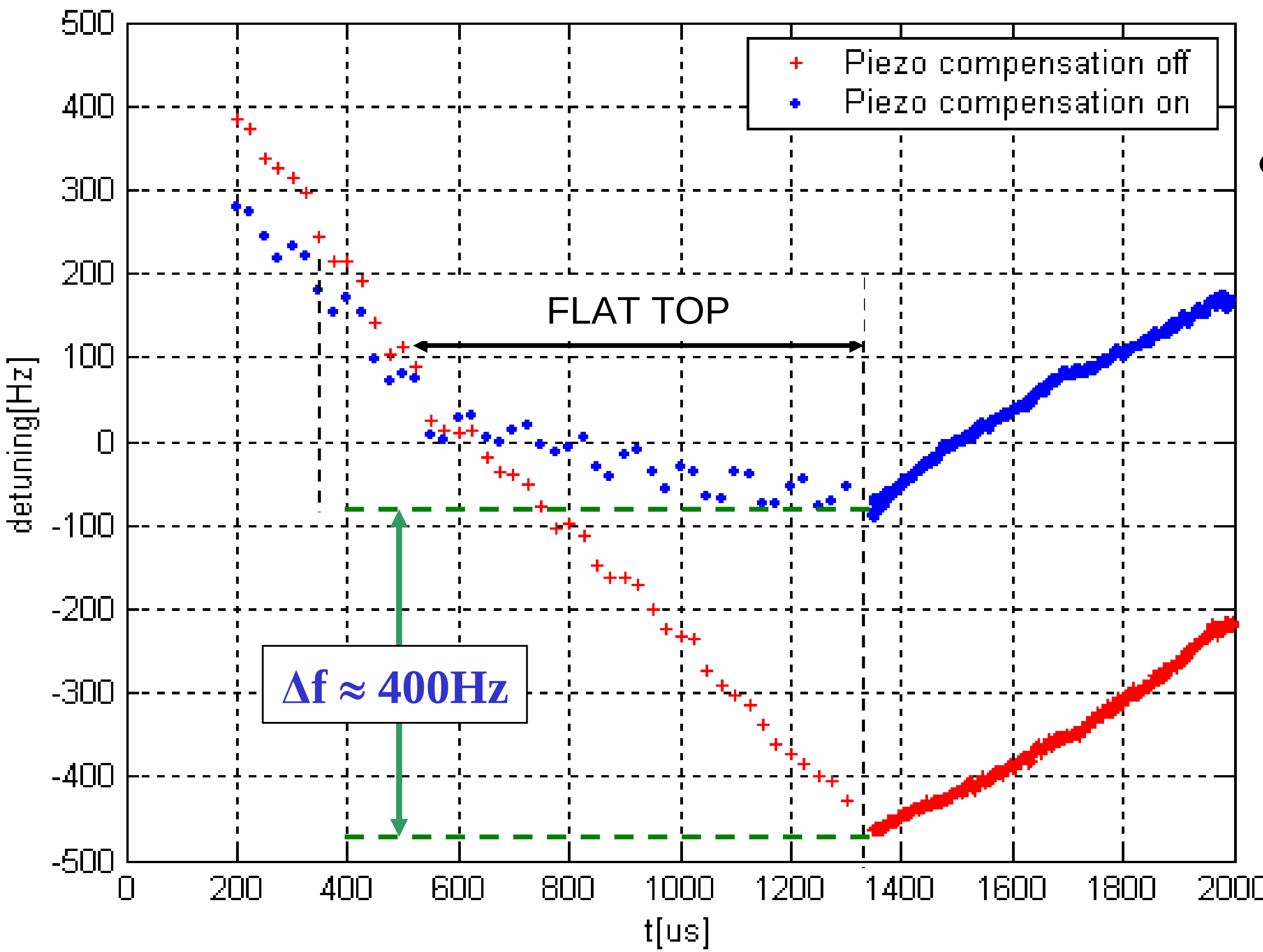
Frequency detuning due Lorentz forces of the electromagnetic field in the cavities:

$\Delta f = -K \bullet E_{acc}^2$

where K ≈ 1 Hz / $(MV/m)^2$

Remember: Cavity bandwidth with main coupler is ≈ 300 Hz

Compensation of Frequency Detuning



- Cavity gradient is 35 MV/m

Summary

- Several electropolished nine-cell cavities have shown gradients of 35 MV/m and higher. Some of these have been prepared without 1400°C firing thus potentially simplifying the cavity preparation procedures.
- Electropolishing will be the method of surface preparation for the XFEL.
- 35 MV/m have been achieved in a high power test of TESLA cavities fulfilling requirements for breakdowns and quenches.
- No degradation has been observed in neither the cavity nor the coupler as is expected for superconducting cavities.
- Active compensation of the frequency detuning during the RF pulse (Lorentz-force detuning) has been demonstrated.
- 35 MV/m have been reached in a cavity inside an accelerator module.
- The test of a full accelerator module is planned for 2005/2006