Superconducting Accelerating Cavities

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DESY -MPY-

Extended Scientific Council

2.6.2005

- Why Superconducting Accelerating Cavities ?
- Limiting Mechanisms
- High Gradients in Superconducting Cavities

Some of the Features of SC Technology

- The large cavity aperture and long bunch interval reduce the complexity of operations, reduce the sensitivity to ground motion, permit inter-bunch feedback and may enable increased beam current.
- The main linac rf systems, the single largest technical cost elements, are of comparatively lower risk.
- The construction of the superconducting XFEL free electron laser will provide prototypes and test many aspects of the linac.
- The industrialization of most major components of the linac is underway.
- The use of superconducting cavities significantly reduces power consumption.

Both technologies have wider impact beyond particle physics. The superconducting rf technology has applications in other fields of accelerator-based research, while the X-band rf technology has applications in medicine and other areas.

Surface Resistance $R_S(T)$

Geometry factor:

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

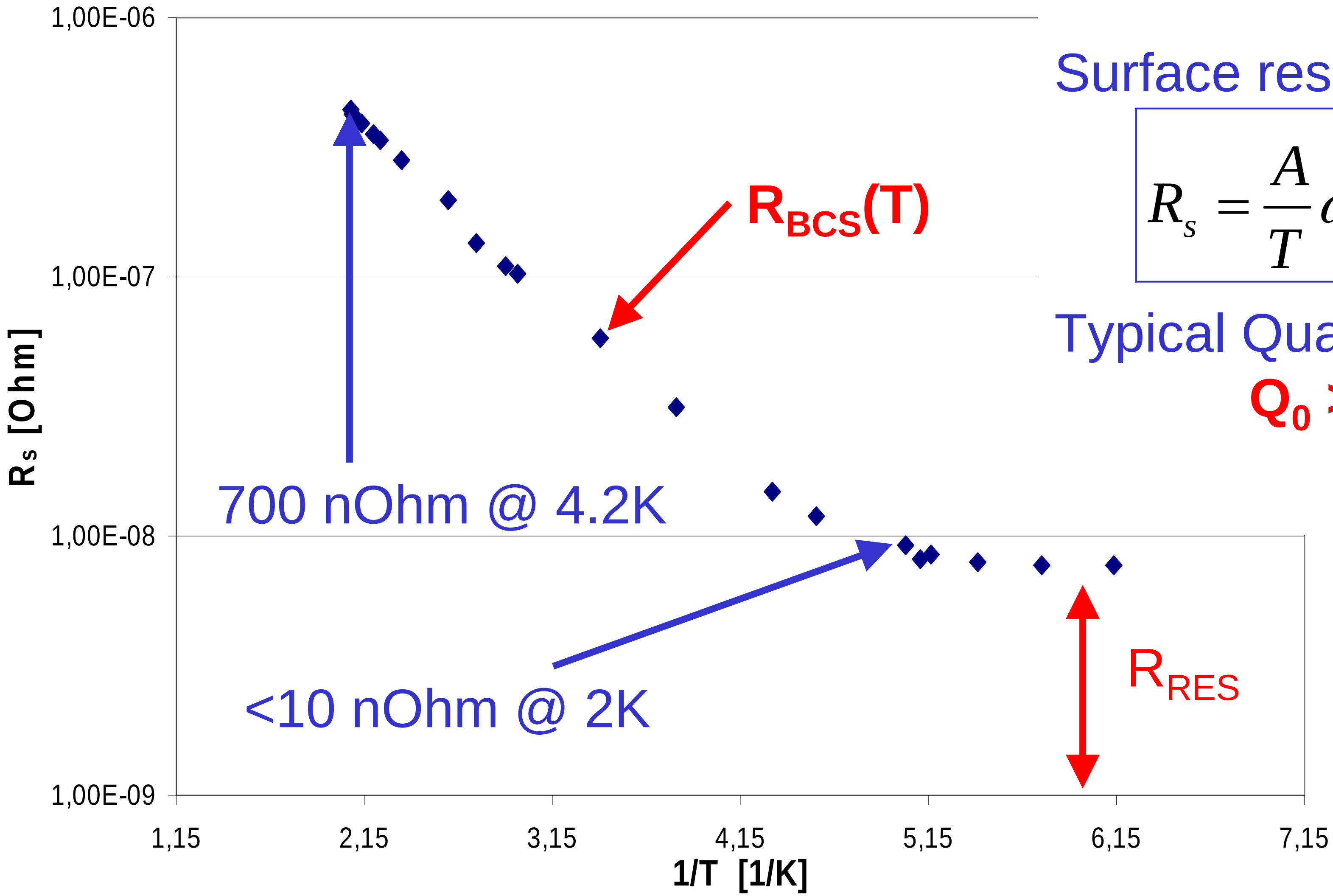
G = 270 Ohm

Surface resistance:

$$R_s = \frac{A}{T}\omega^2 e^{-\frac{\Delta}{k_B T_C}\frac{T_C}{T}} + R_{res}$$

Typical Quality factor:

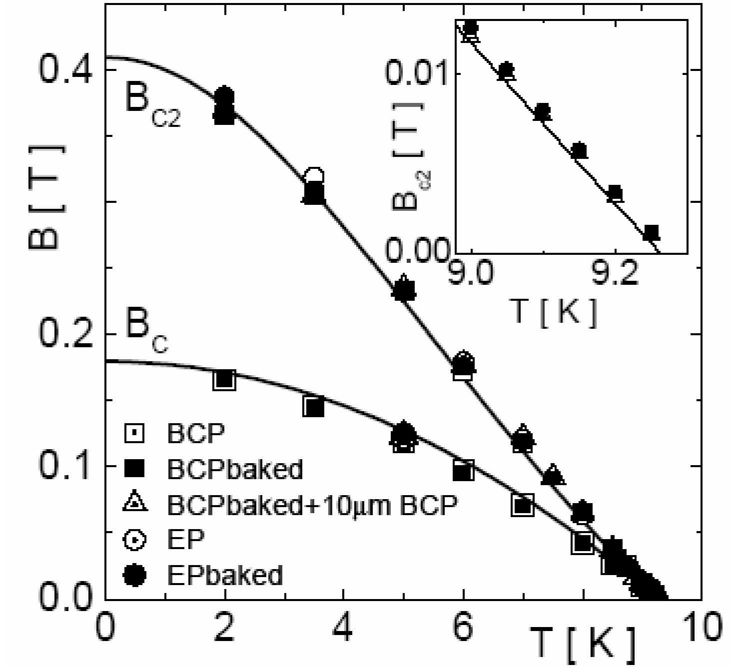
$Q_0 > 1*10^{10}$ at 2K



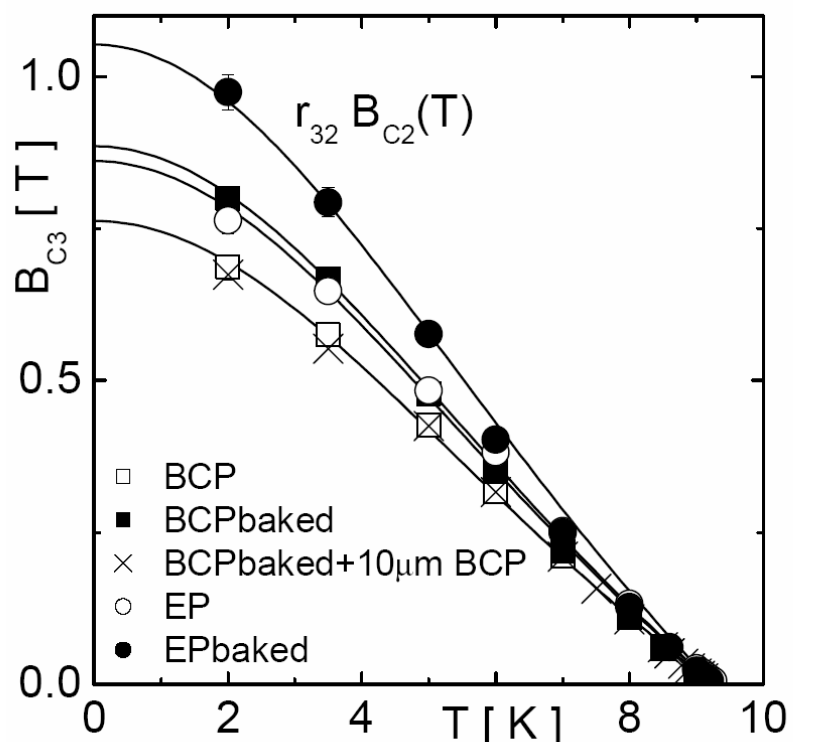
S. Casalbuoni,
L. von Sawilski,
P. Schmüser,
B. Steffen et al.

Susceptibility Measurements: Niobium Properties

- Surface treatment does not change the bulk properties e.g. B_c and B_{c2}
- Surface critical field B_{c3} depends on surface preparation
  - EP vs. BCP
  - Baking

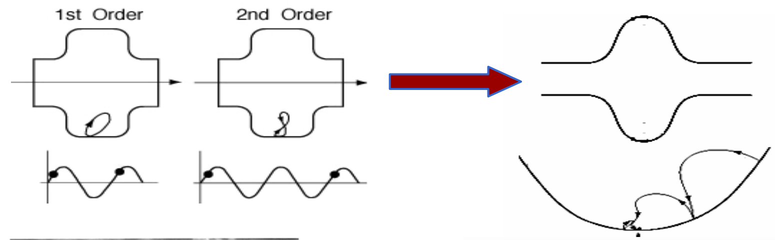


	BCP	EP
T_c [K]	9.263 ± 0.003	
RRR	≈ 300	
surf. roughness on grain [nm]	≈ 1	
steps at grain bound.	1-5 μm	$\lesssim 0.1 \mu$m
$B_c(0)$ [mT]	180 ± 5	
$B_{c2}(0)$ [mT]	410 ± 5	
$J_c(0,0)$ [A/mm^2]	240 ± 10	180 ± 10

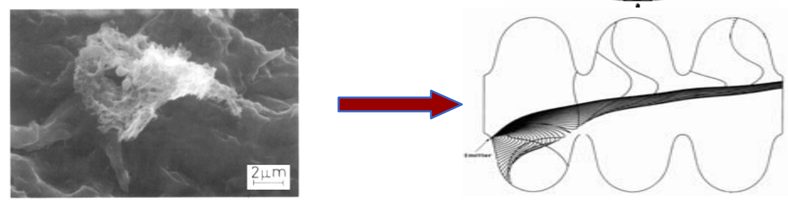


Examples for Limiting Mechanisms

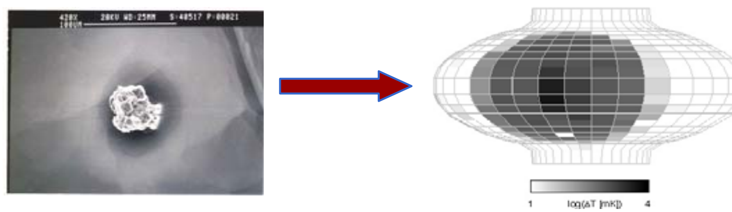
- Understanding Multipactoring
  - Computer codes were developed
  - Spherical shape realized at Genova and qualified at Cornell & Wuppertal



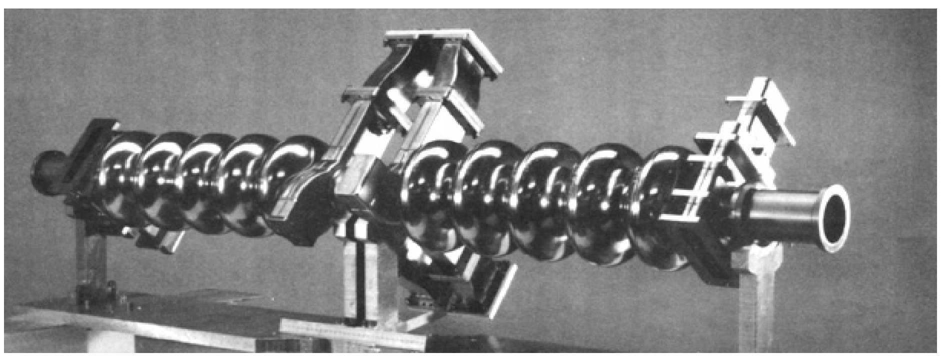
- Understanding Field Emission
  - Emitters were localized and analyzed
  - Improved treatments and cleanliness



- Cure thermal Breakdown
  - Higher RRR Nb
  - Deeper control for inclusions



E_{acc} > 5 MV/m



1984/85: First great success

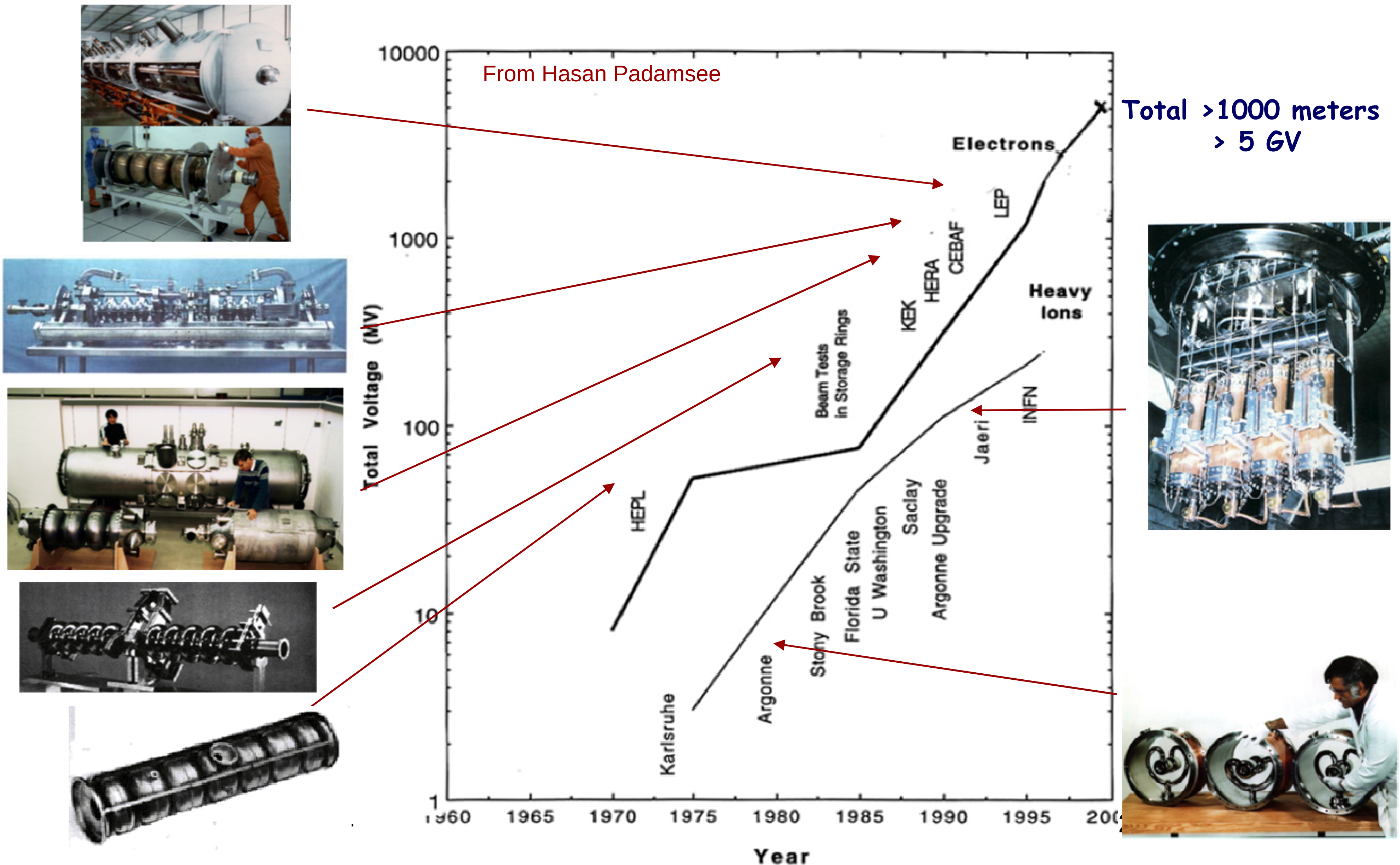
- A pair of 1.5 GHz cavities developed and tested (in CESR) at Cornell
- Chosen for CEBAF at TJNAF for a nominal E_{acc} = 5 MV/m

Cleanroom Technology for SC Cavities

- the small surface resistance of the superconducting necessitates avoidance of NC contaminations larger than a few mm
    - detailed material specification and quality control are done
    - tight specification for fabrication e.g. welds have been implemented
    - clean room technology is a must (e.g. QC with particle counts, monitoring of water quality, documentation of processes)

The inter-cavity connection is done in class 10 cleanrooms

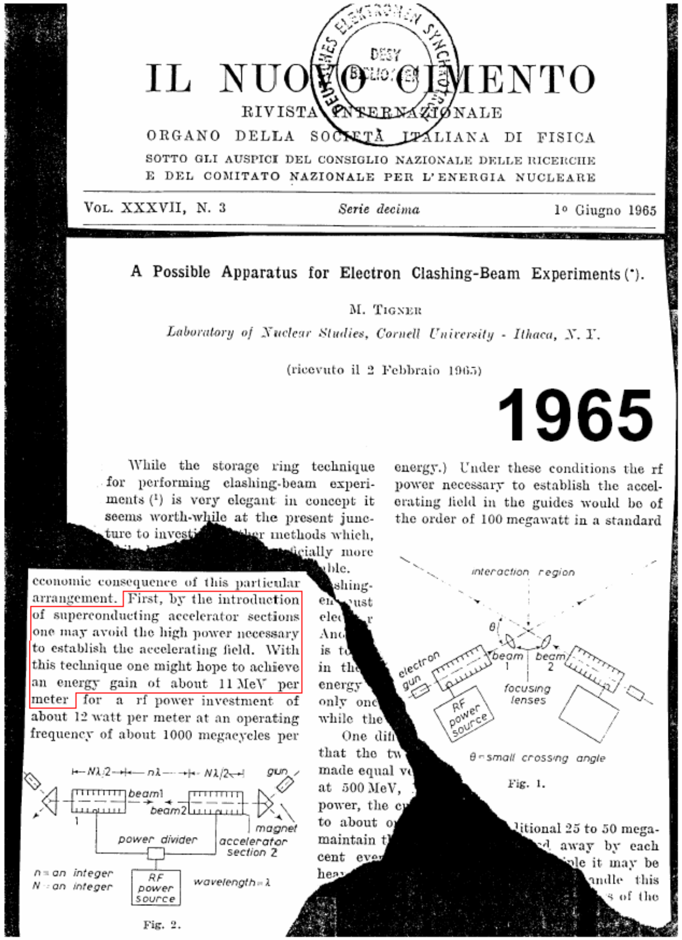
SRF: Installed Accelerating Voltage



New Applications for SRF Cavities

- high energy physics and synchrotron radiation physics (chemistry, biology...) have taken profit of this technology already since a long time
- new projects are aiming at
  - highest gradients (e.g. ILC)
    - further improvement of the surface preparation
  - increasing electron currents (ERLs)
    - Higher-Order-Mode (HOM) damping
  - high duty cycle (CW FELs)

The ILC in 1965



IL NUOVO CIMENTO
RIVISTA INTERNAZIONALE
ORGANO DELLA SOCIETÀ ITALIANA DI FISICA
SOTTO GLI AUSPICI DEL CONSIGLIO NAZIONALE DELLE RICERCHE
E DEL COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
VOL. XXXVII, N. 3 Serie decima 1° Giugno 1965

A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER
Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(ricevuto il 2 Febbraio 1965)

1965

While the storage ring technique for performing clashing-beam experiments (1) is very elegant in concept it seems worth-while at the present juncture to invest... ...her methods which, ...cially more ...ble.

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energy.) Under these conditions the rf power necessary to establish the accelerating field in the guides would be of the order of 100 megawatt in a standard

Fig. 1.

Fig. 2.

M. Tigner, A Possible Apparatus for Electron Clashing-Beam Experiments Il Nuovo Cimento Vol. XXXVII, No.3 (1965)

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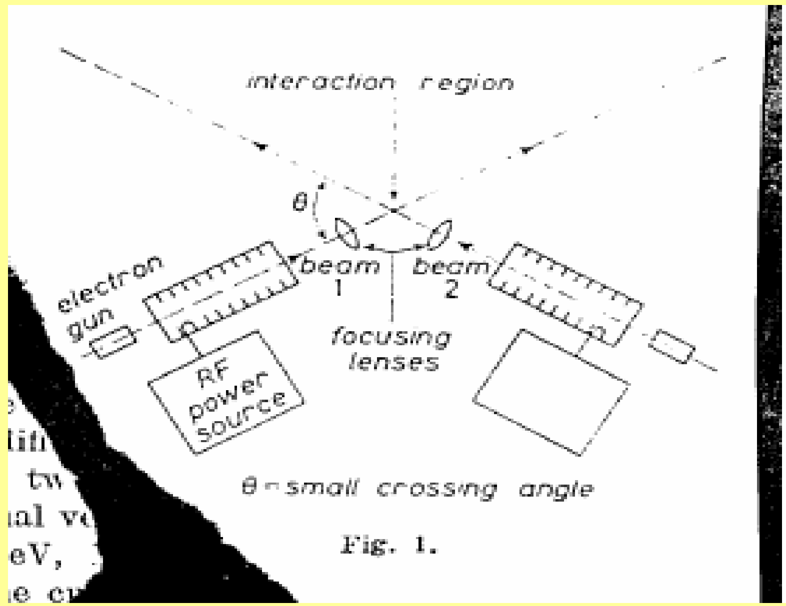
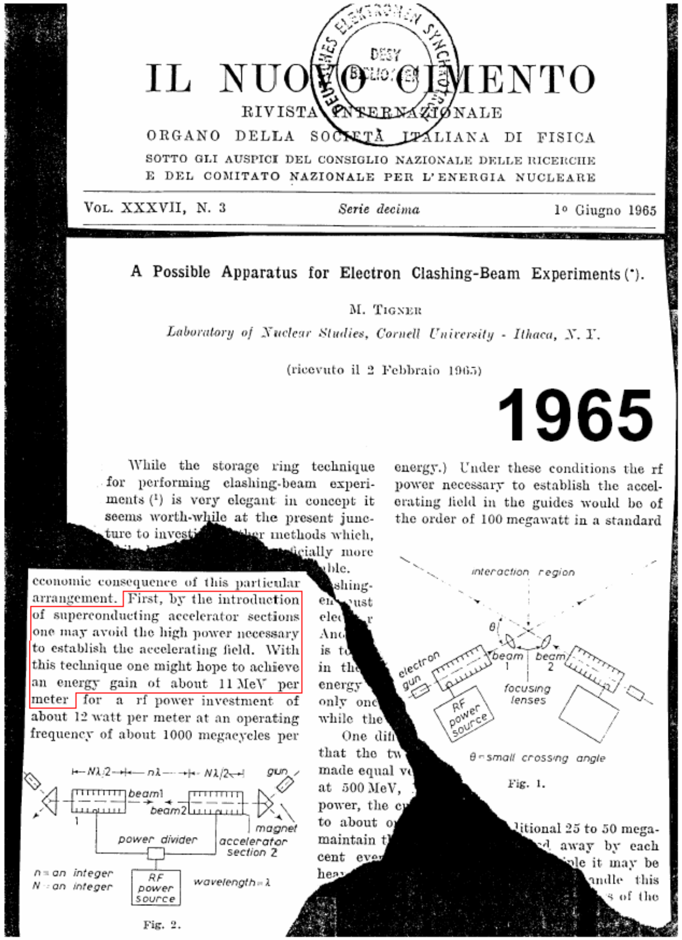


Fig. 1.

The ILC Today



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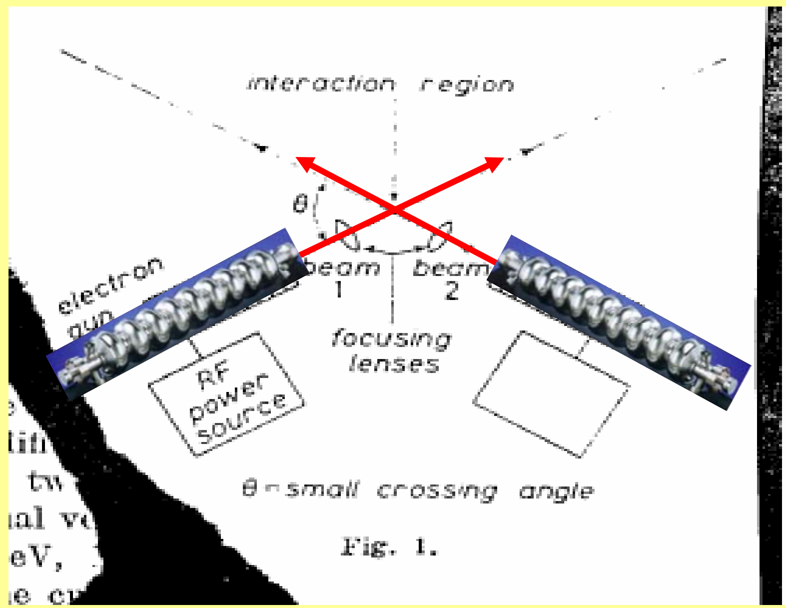
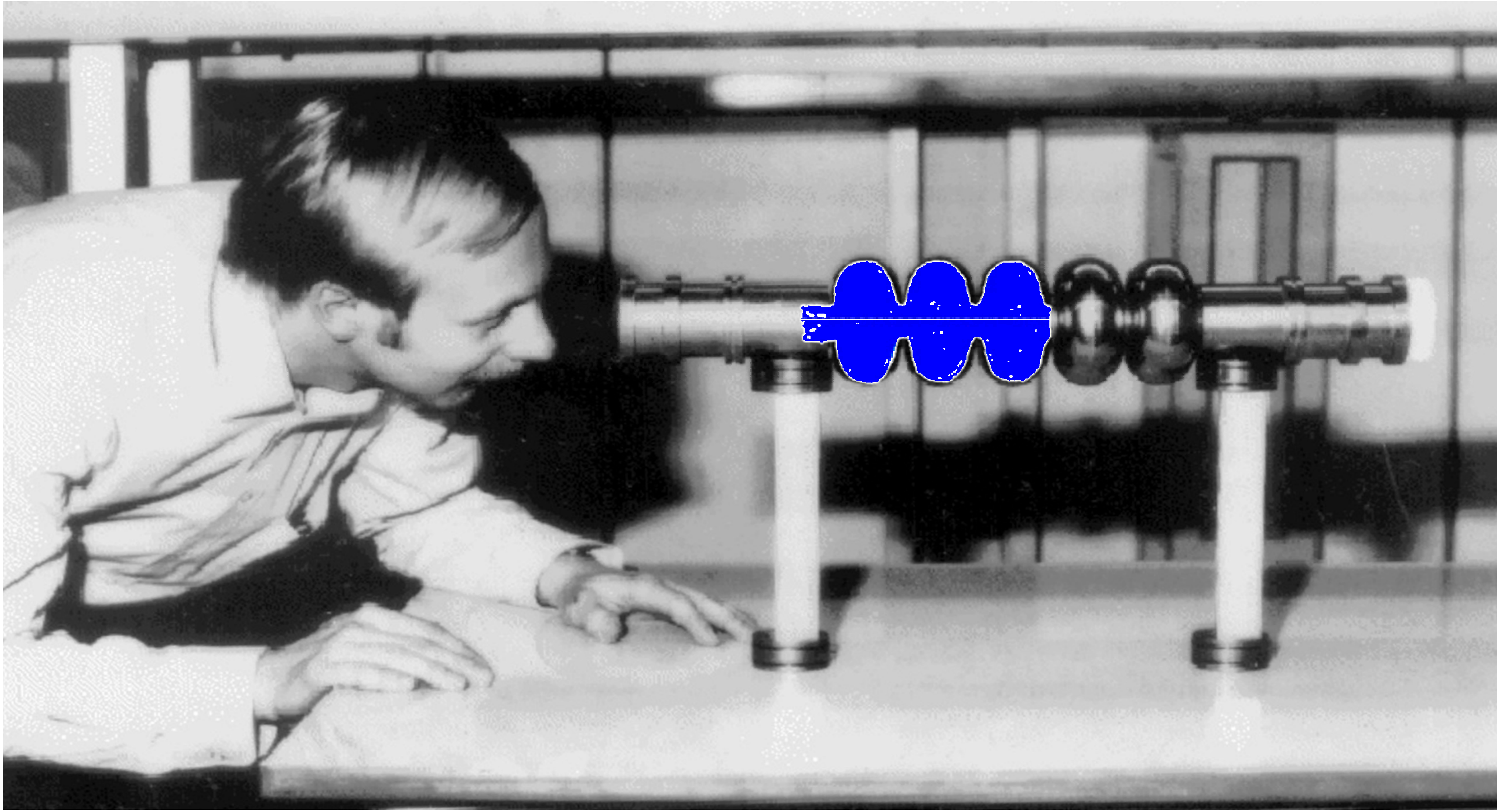


Fig. 1.

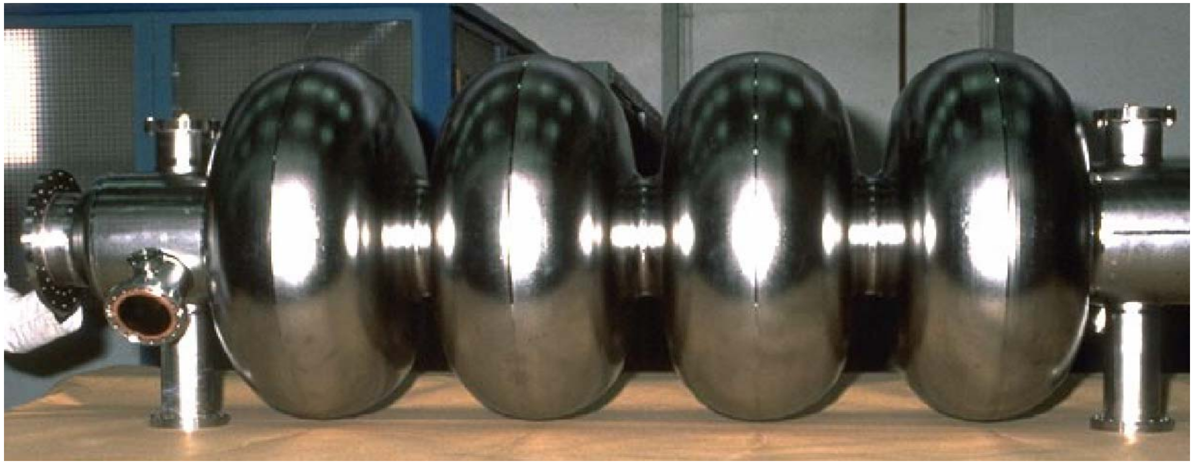
But What is the Frequency to Choose?

352 MHz?

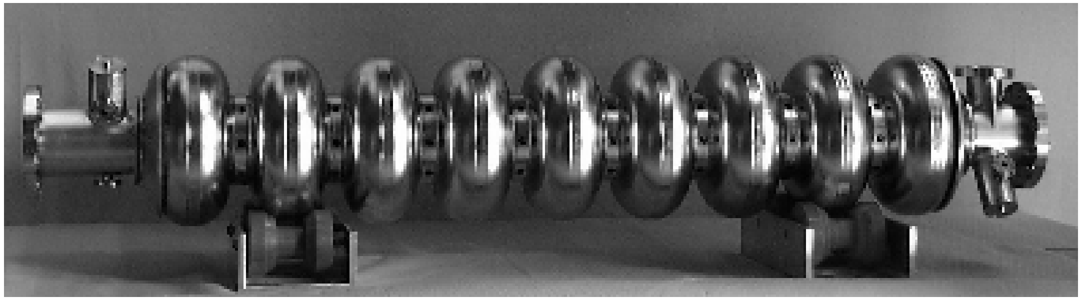
3 GHz ?



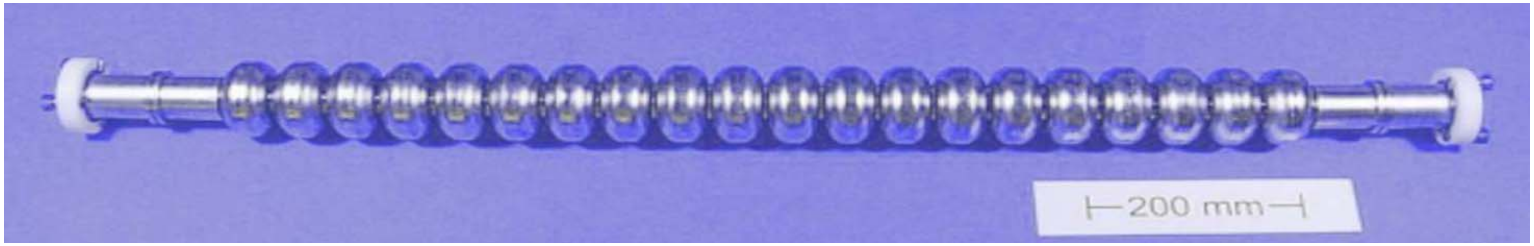
1.3 GHz!



352 MHz
LEP



1300 MHz
TESLA



3000 MHz
S-DALINAC

Towards Ultimate Gradients

- Optimum niobium quality and surface preparation improvement has been essential for higher gradients
- This started within the TESLA Collaboration in 1990
  - Goals were
    - Increase the gradient by factor 5 (from 5MV/m to 25 MV/m)
    - Reduce cost by a factor of 4
  - Best ‘Standard’ process steps taken from all over the world: Uni Wuppertal, CEA Saclay, Cornell, CERN…

Bjoern Wiik and the Push Towards Gradients Above 25 MV/m (1997)…

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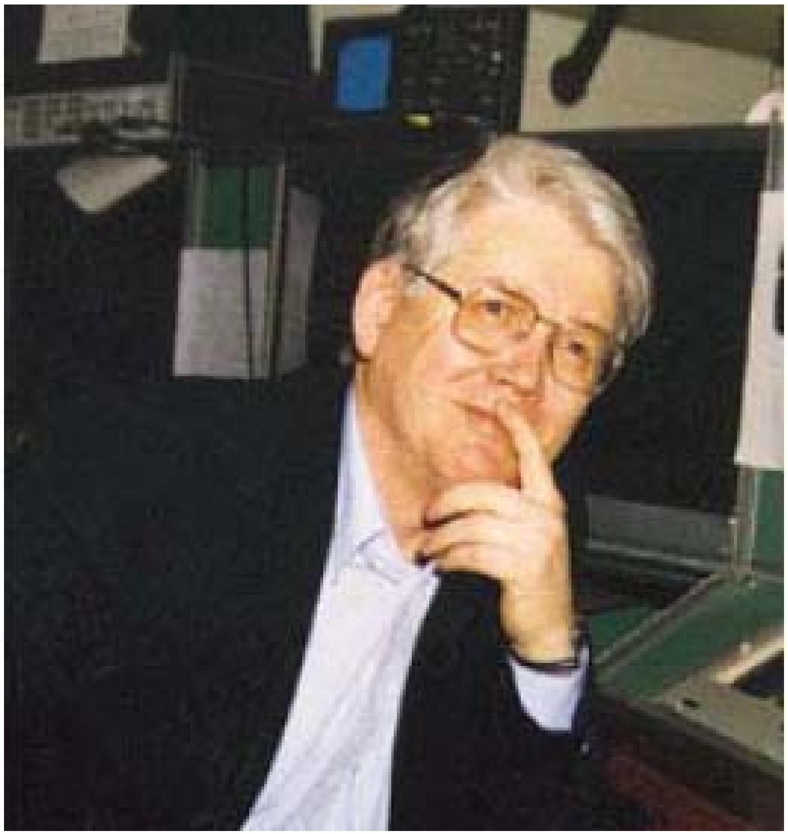
Nuclear Instruments and Methods in Physics Research A 398 (1997) 1–17

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

The TESLA project: an accelerator facility for basic science

B.H. Wiik

DESY and the University of Hamburg, Hamburg, Germany



available. Based on the steady progress in the performance of superconducting cavities it seems reasonable to assume that in the next decade cavities with accelerating gradients of order 40 MV/m will be at hand. Gradients close to 40 MV/m have already been reached [19] in single cell cavities.

… and towards the TDR

S2

ECFA DESY
Linear Collider Workshop

2nd ECFA/DESY Study on Physics and Detectors for a Linear Electron-Positron Collider

LAL - Orsay - France, April 5-7, 1998

Date : April 5, 1998 - 14:10

Speaker : B. Wiik

Strategic background

Status Cavities

- Nb - material as presently available and present production and processing techniques will yield cavities which meets the TESLA goals (25MV/m, 5·10

- Strict quality control of Nb sheets and of the production / processing steps are needed to consistently produce TESLA quality cavities.

  ↦ Next series of 26 cavities will answear this question

↦ finalize production and procesing procedures. Industrial Study of welded cavities is underway

↦ Cavities produced by spinning or hydro forming. cheaper and more reliable.

↦ Effort to reach higher gradients
- better material
- "new" processing methods (electropolishing)

Performance of Accelerator Module 5

A State-of-the-art module

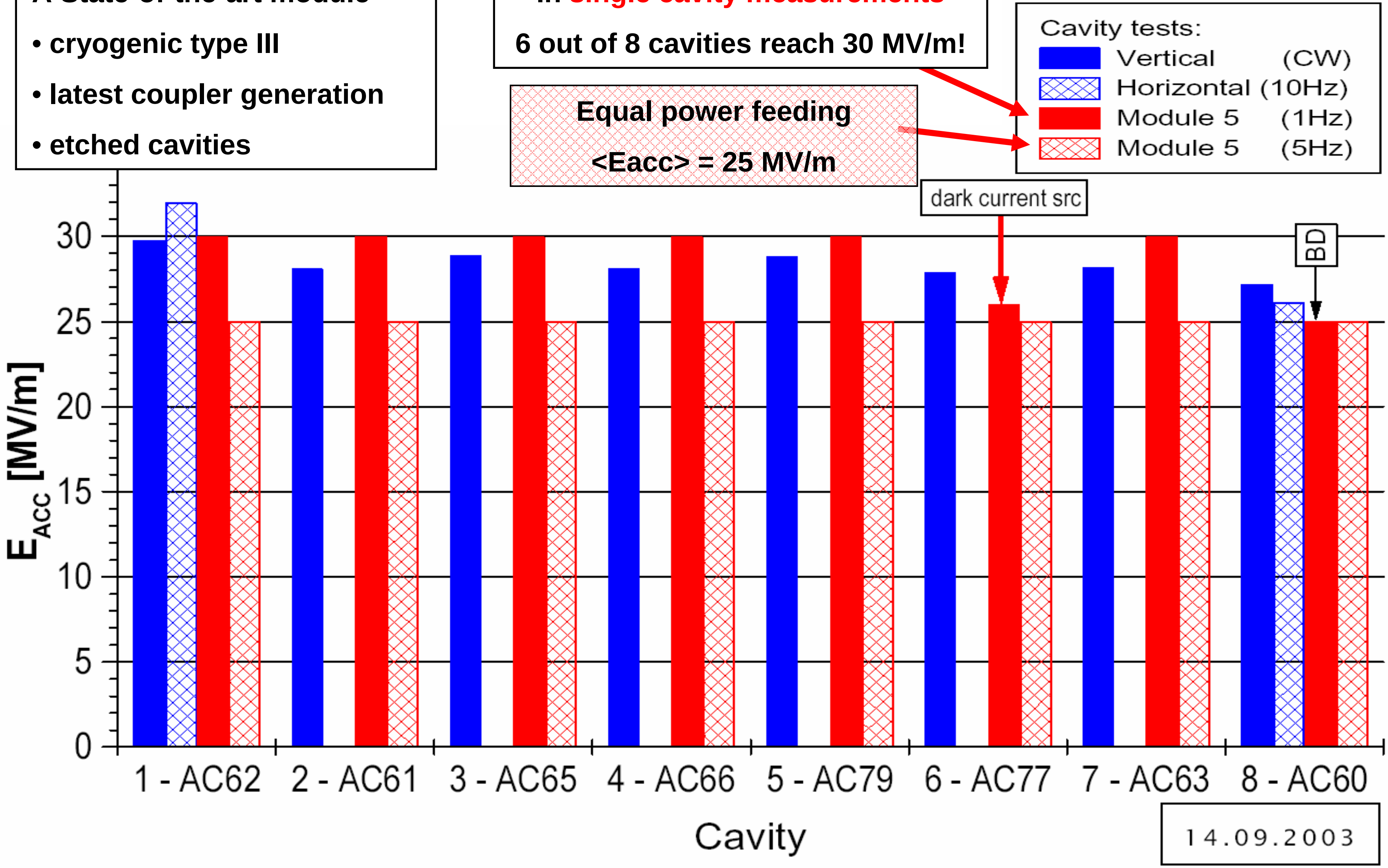
- **cryogenic type III**
- **latest coupler generation**
- **etched cavities**

In single cavity measurements

6 out of 8 cavities reach 30 MV/m!

Equal power feeding

<Eacc> = 25 MV/m



First Single-Cell Cavities at 1.3 GHz

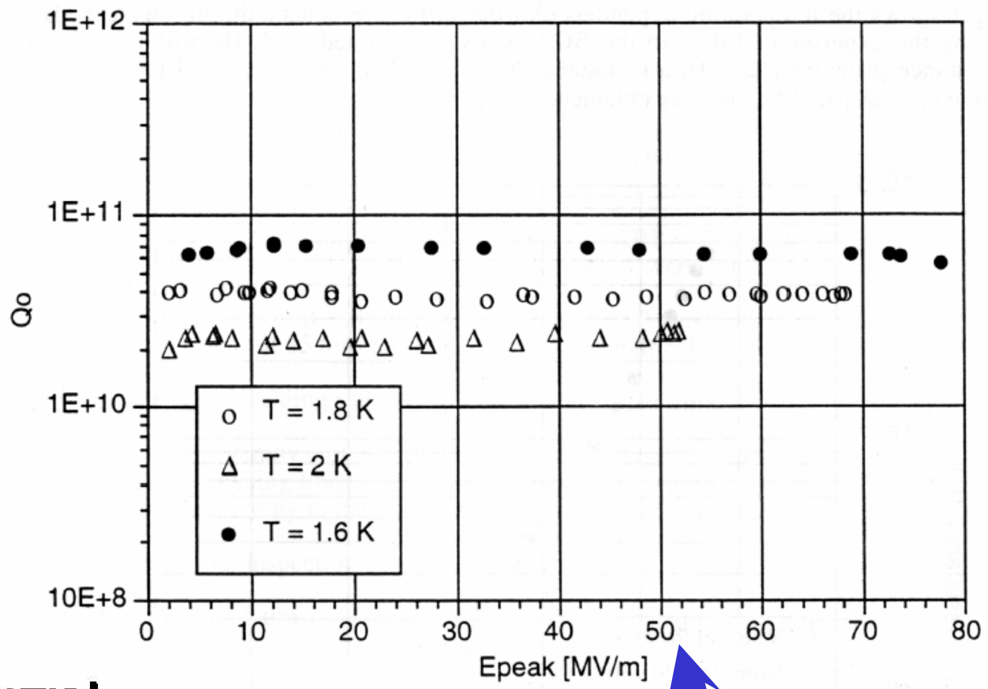
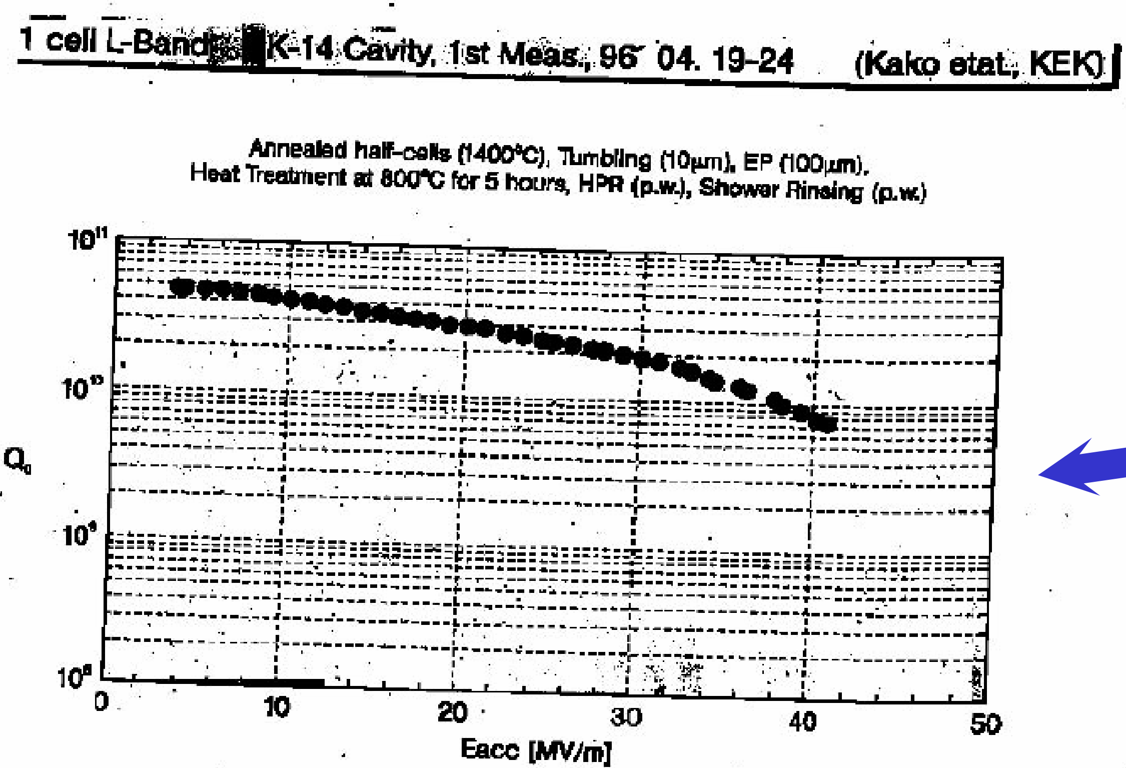


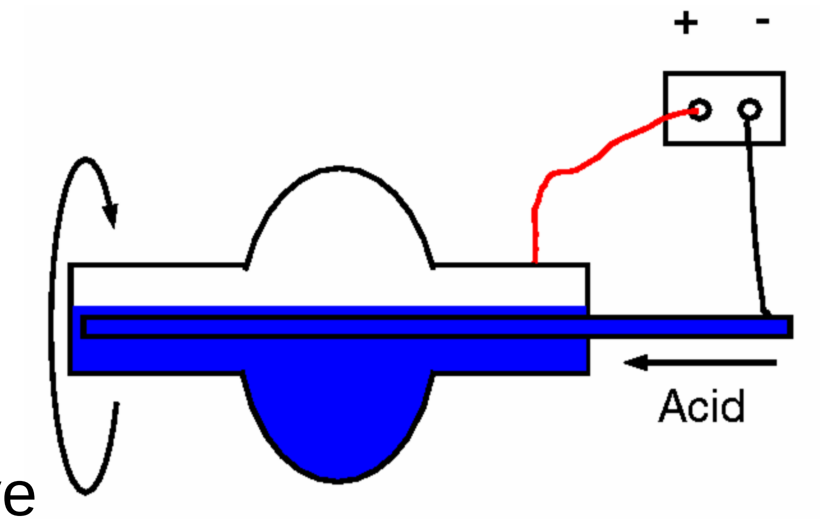
Fig. 2: Qo vs. Epeak at 3 different temperatures for a nearly "defect - free" niobium cavity



- 1995: Single-cell test with 40 MV/m from standard etch preparation (Kneisel et al.)
- 1996: an electropolished single-cell cavity at KEK (Kako, Saito et al.) achieved also 40 MV/m

02.06.2005

Surface Preparation: Electropolishing



- Electropolishing (EP) of niobium surfaces is a key technology to achieve the highest electrical and magnetic surface fields
- KEK/ Nomura Plating pioneered application of EP to elliptical niobium cavities since TRISTAN using a Siemens' recipe from the 1970s
- Since then EP has also been successfully applied to
  - Low-Beta Quarter wave structures
  - TESLA nine-cells

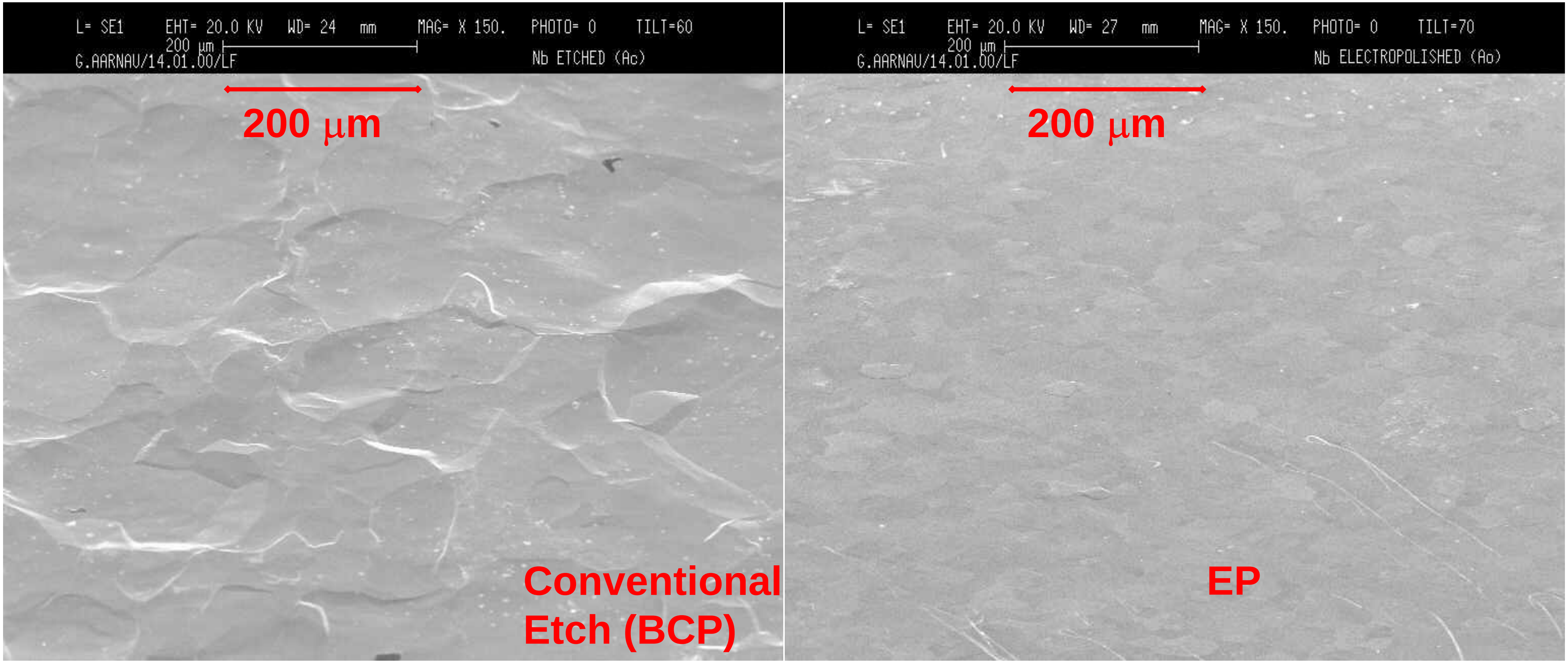
EP Electrolyte (Siemens)

- 90 % H_2SO_4
- 10 % HF
- ~30 °C

EP setup (KEK)

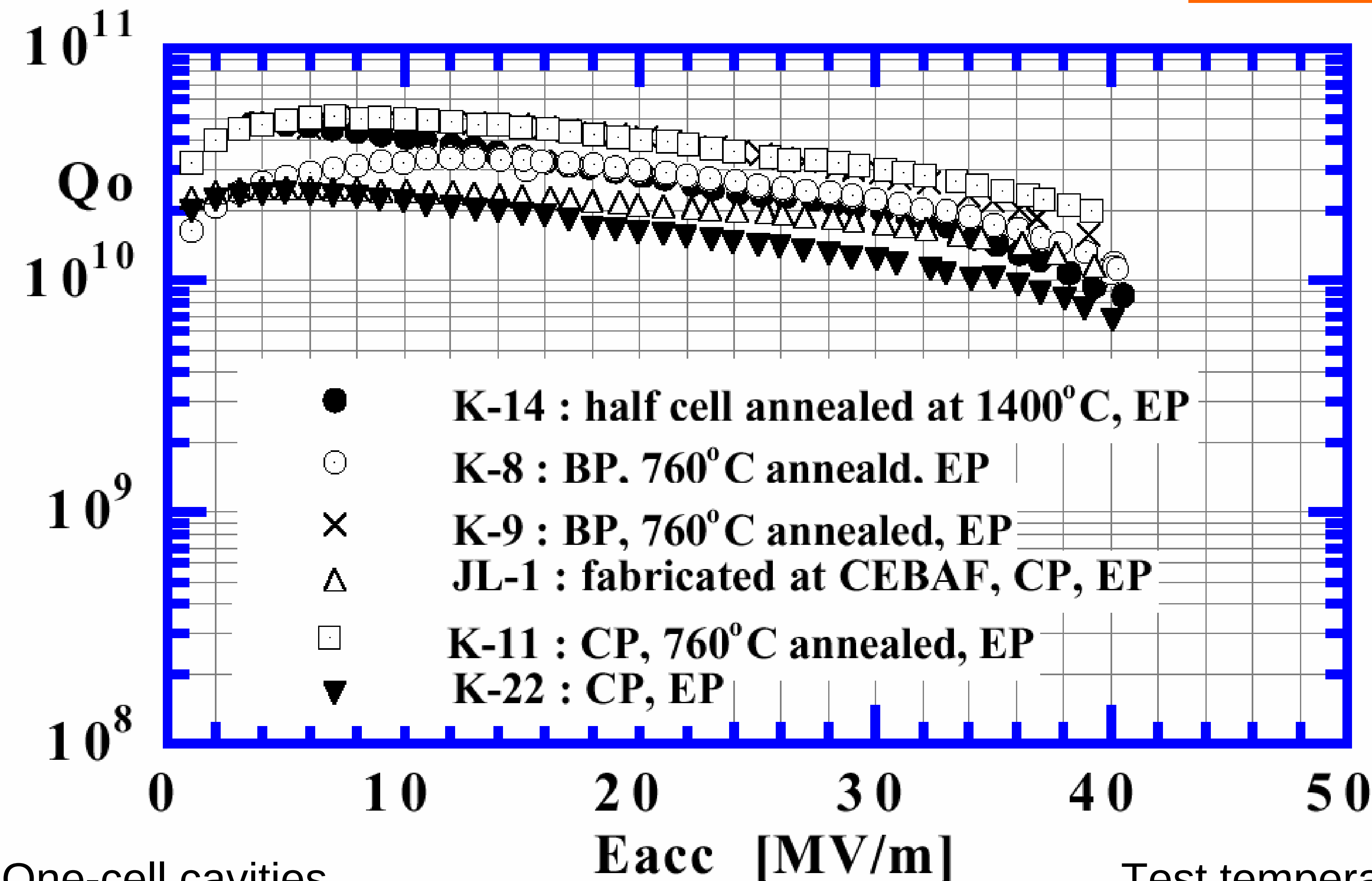
- 0,3 - 0,5 μm/min

Electropolishing Offers Improved Surface Quality



Electropolished 1,3 GHz Elliptical Niobium Cavities

K. Saito et al. KEK 1998/1999

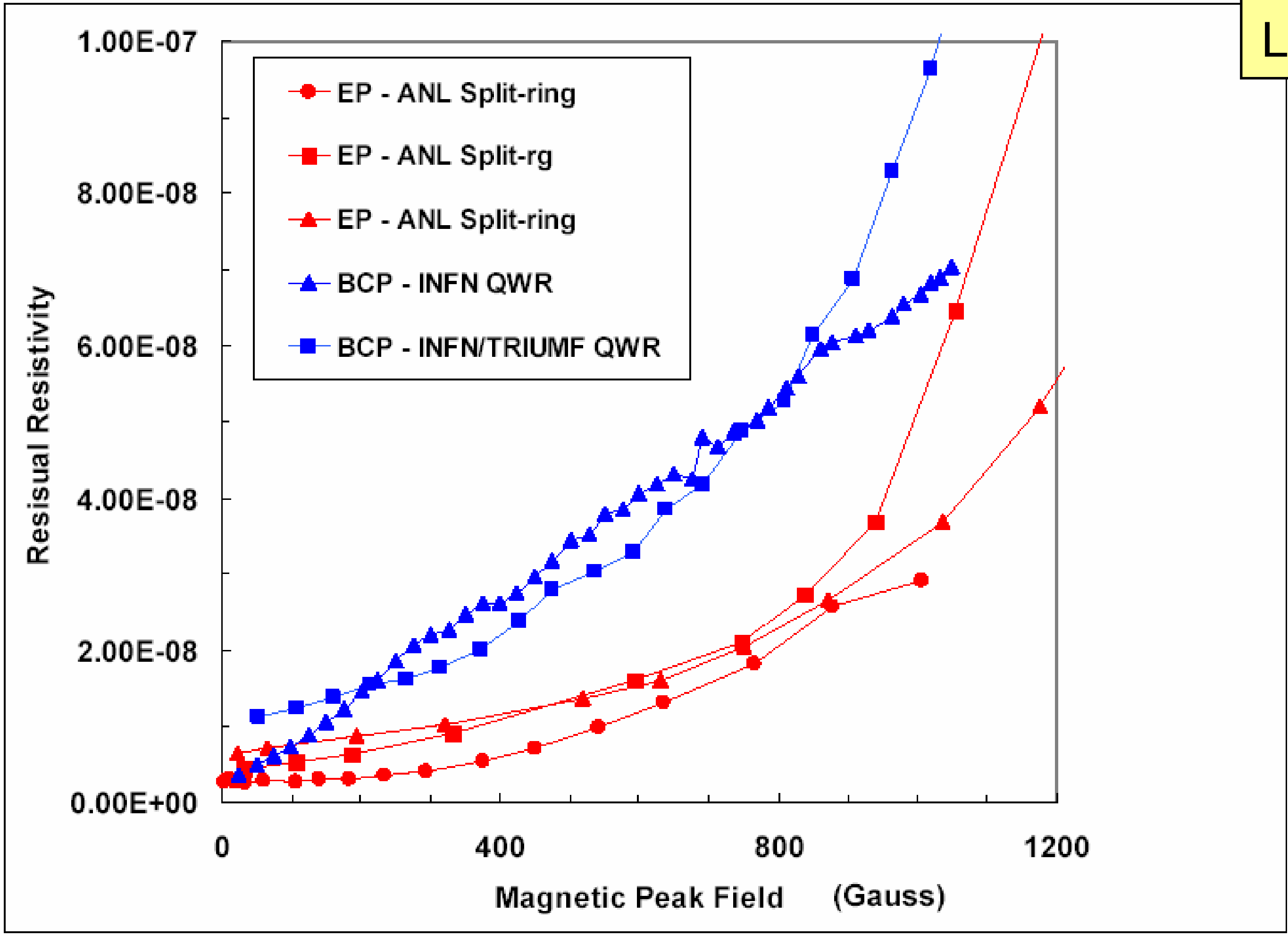


One-cell cavities

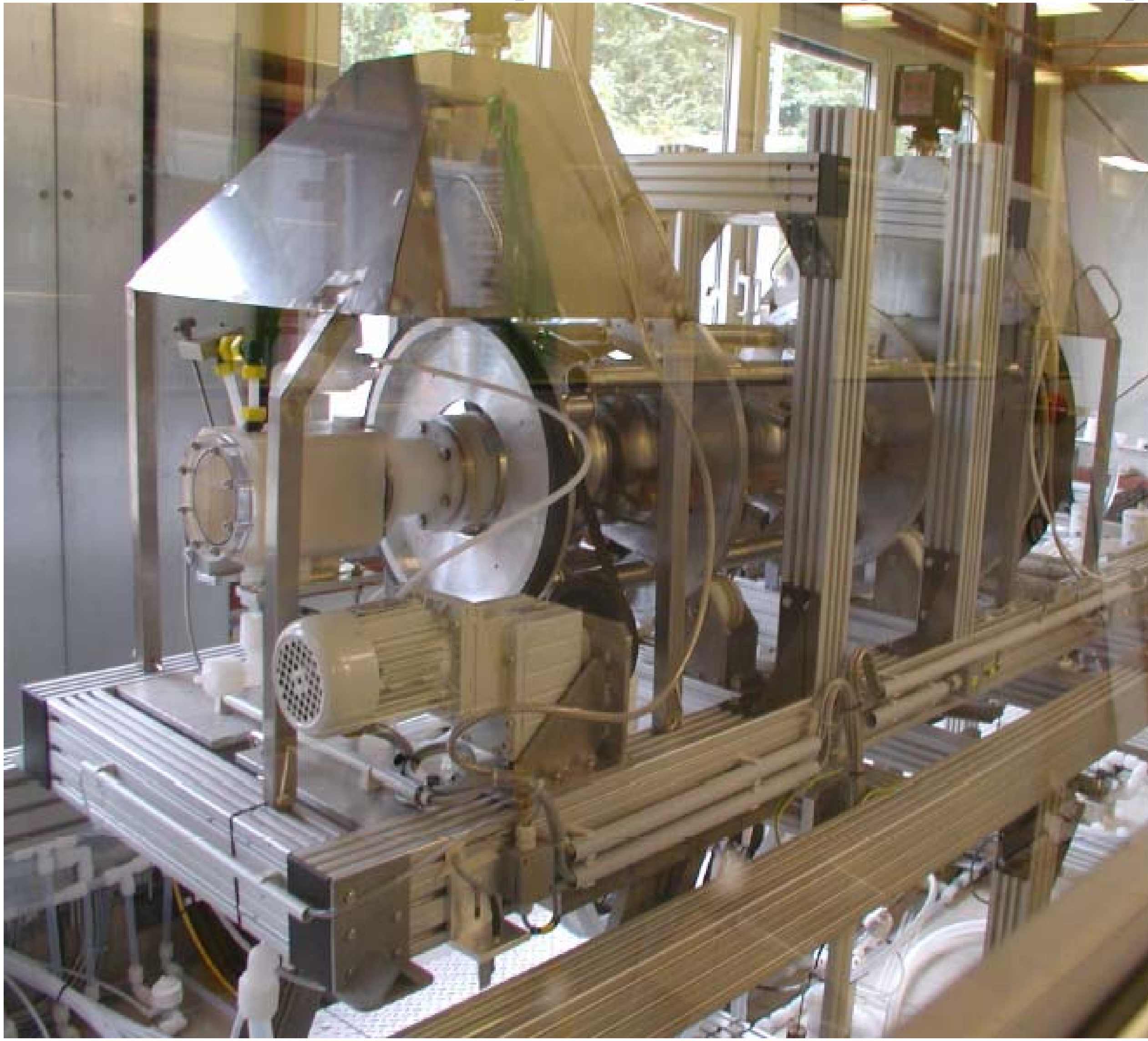
Test temperature: 1.6 K

4.2 K Residual resistivity – 80-100 MHz Quarter-wave structures

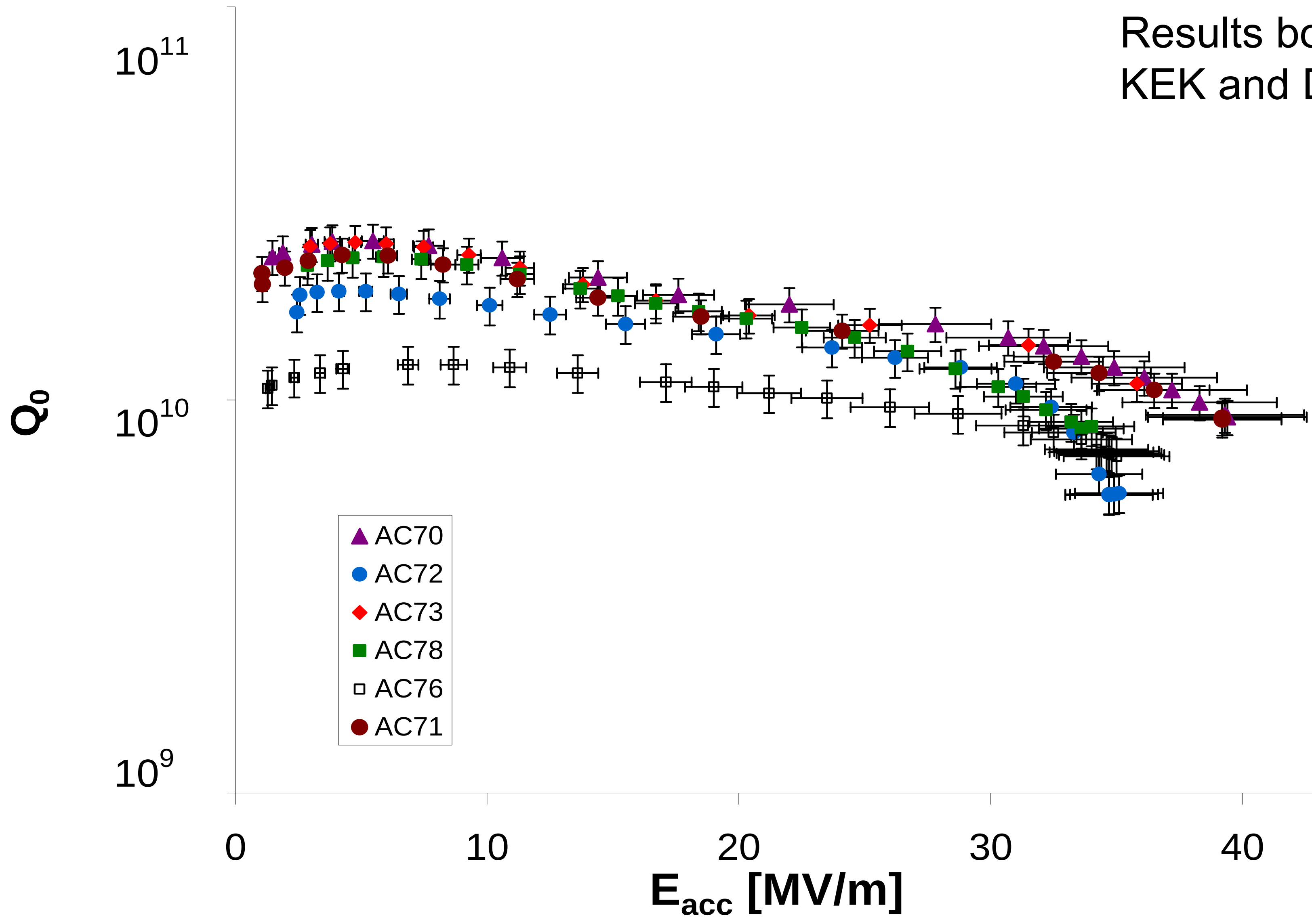
Ken Shepherd,
SRF 2003,
Lübeck



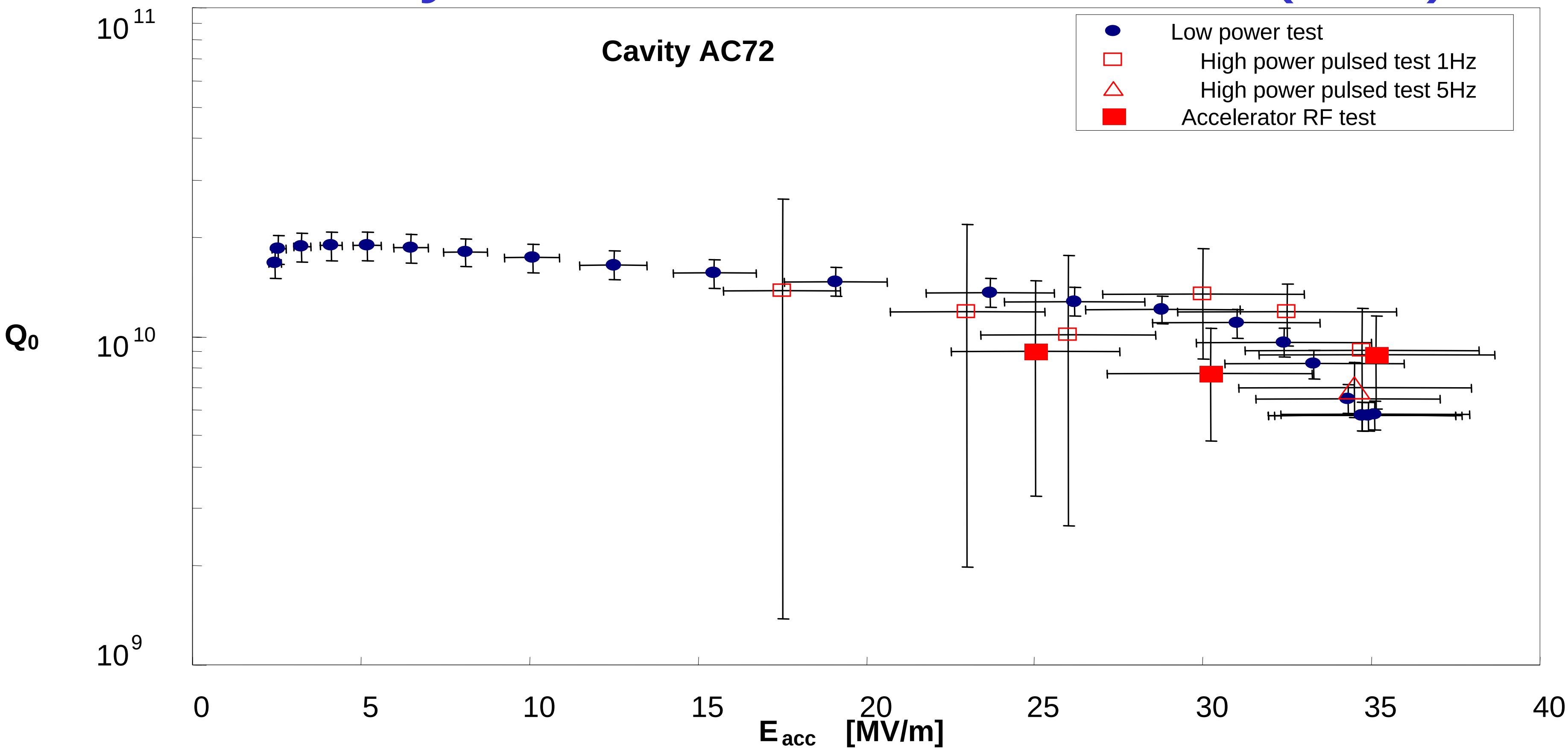
Electropolishing Setup at DESY



Electropolishing: Test Results

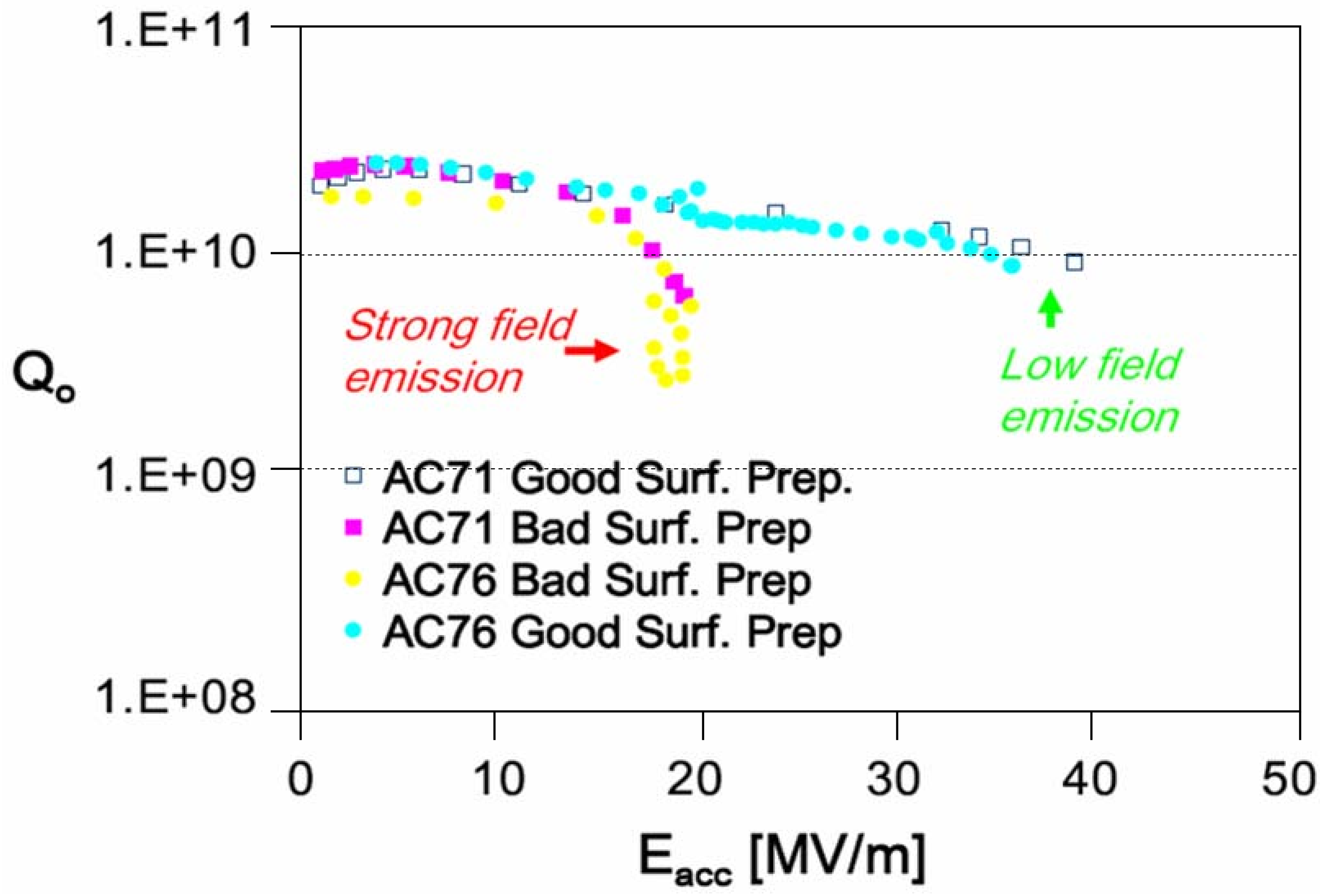


Cavity Test Inside a Module (ctd.)

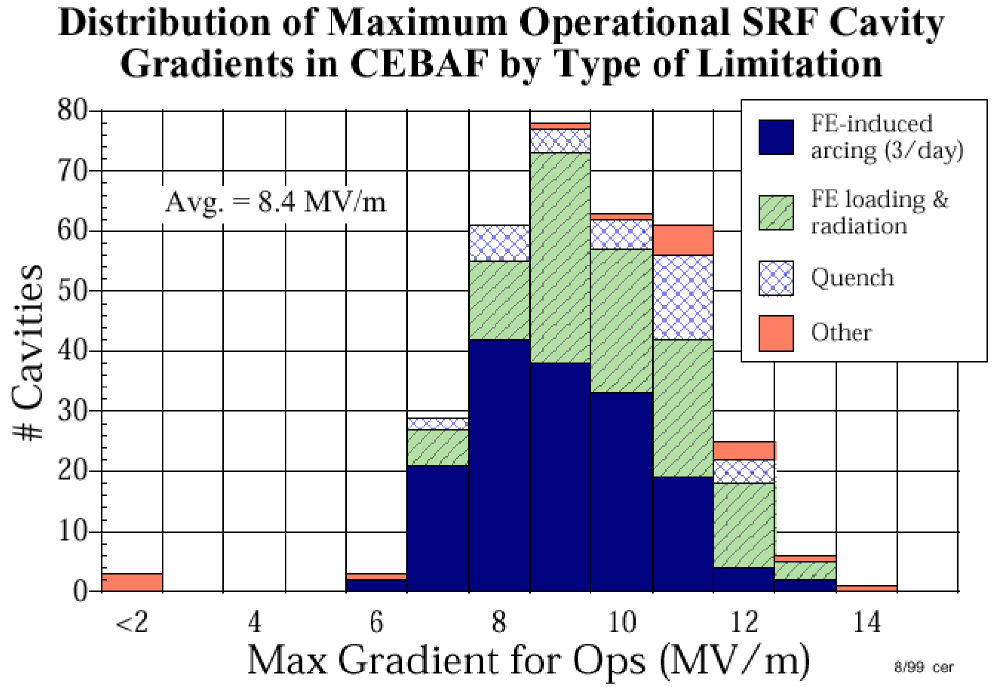


- One of the electropolished cavities (AC72) was installed into an accelerating module for the VUV-FEL
- Very low cryogenic losses as in high power tests
- Standard X-ray radiation measurement indicates no radiation up to 35 MV/m

Problems: Reproducibility in the EP Process



Time evolution of accelerating gradient

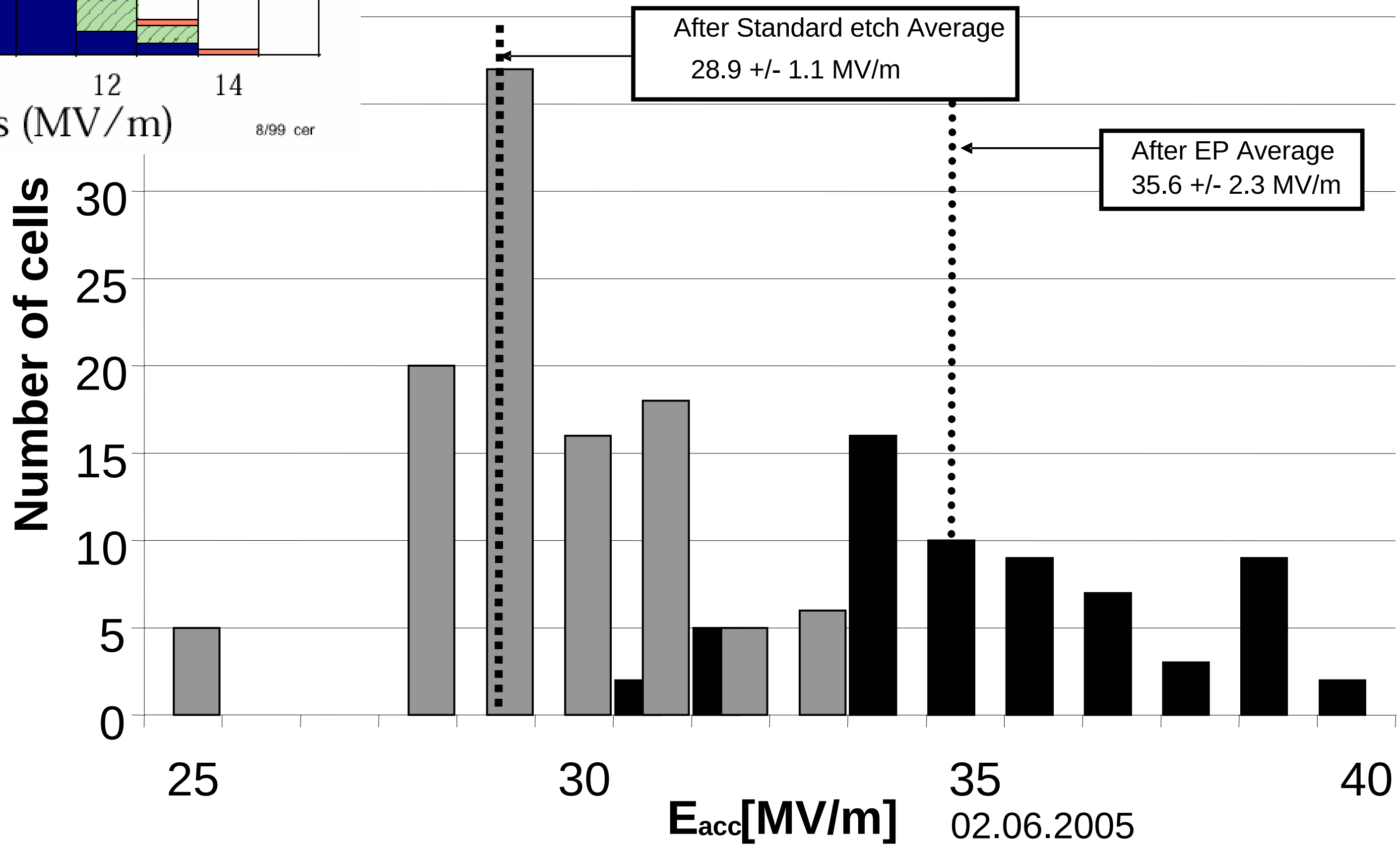


Gradients available in multi-cells before the TESLA collaboration started…

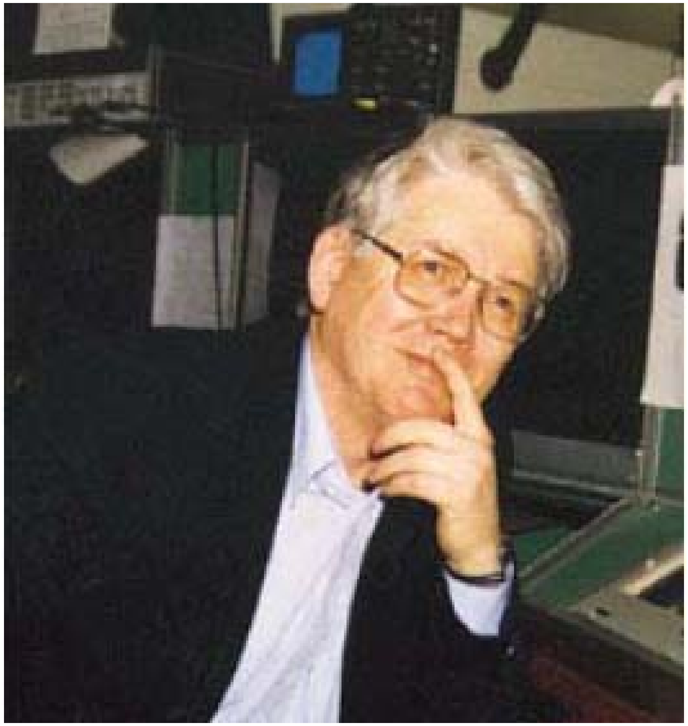
(CEBAF after several years of operation)

… until today:

TESLA Cavities



Bjoern Wiik and the Push Towards Gradients Above 25 MV/m (1997)…



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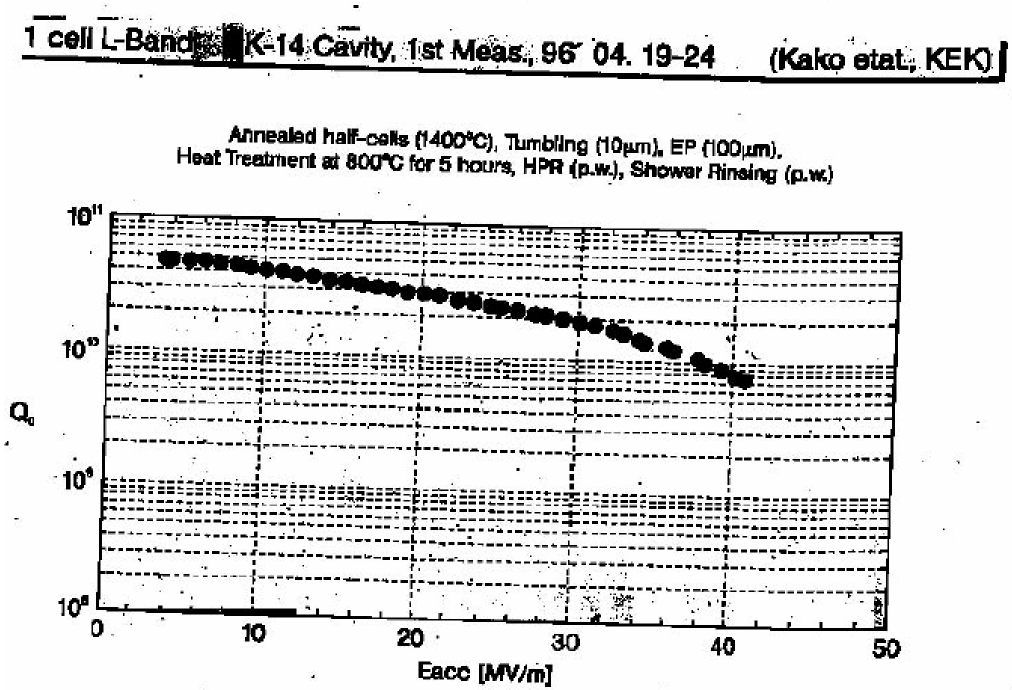
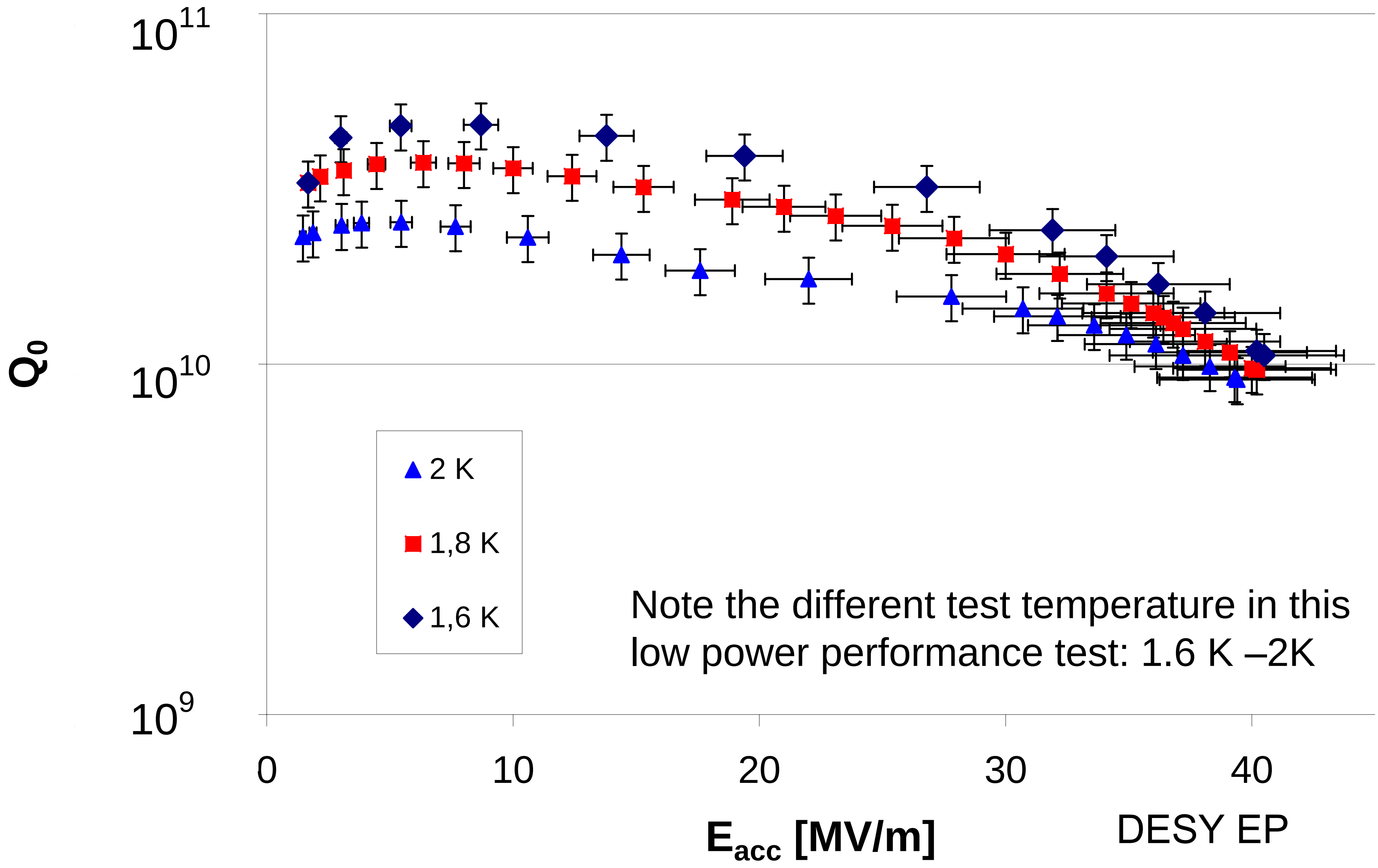
So, what's the status 2 years before the deadline???



Proof-of-Principle Nine-Cell Test



Thank you!