# High Gradient Program for the ILC at DESY

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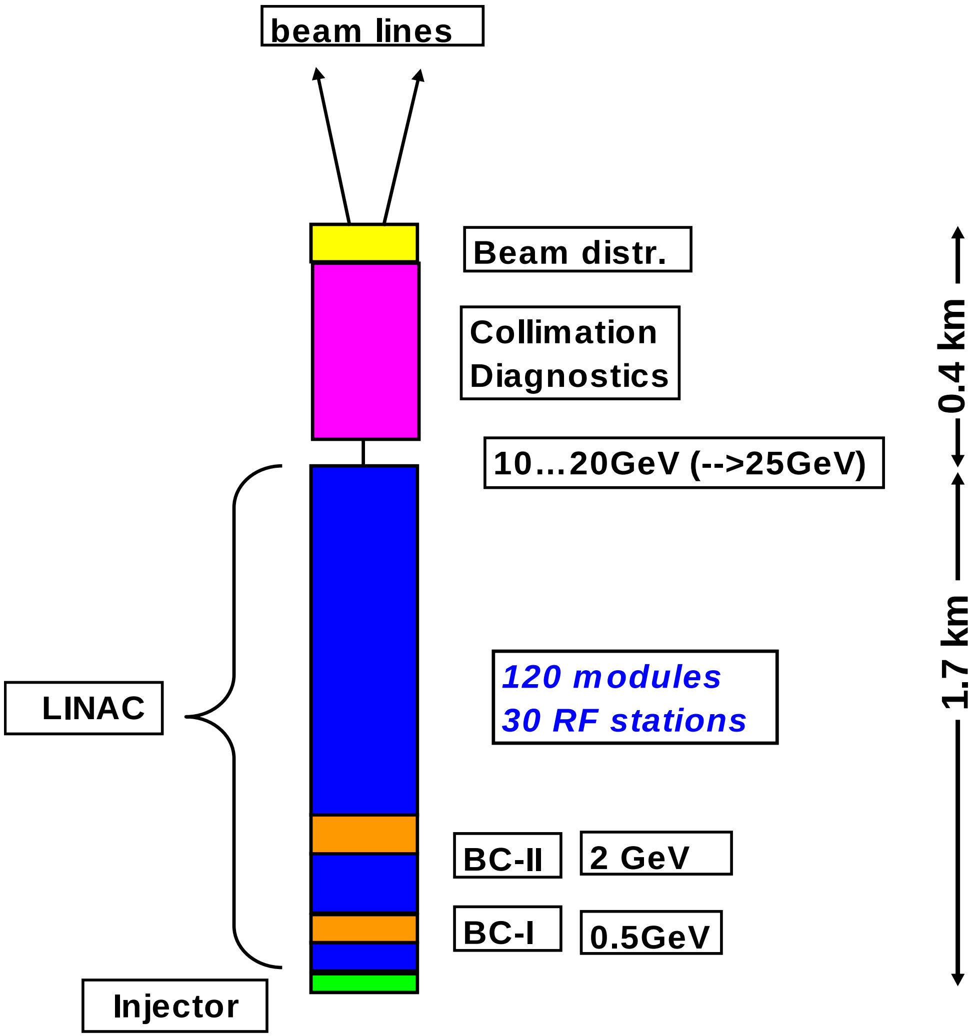
- Overview
- Review on test results for TTF cavities
  - Surface treatments
  - Integration into accelerator modules
- Work on Auxiliaries
  - e.g. Frequency Tuner

# DESY Program

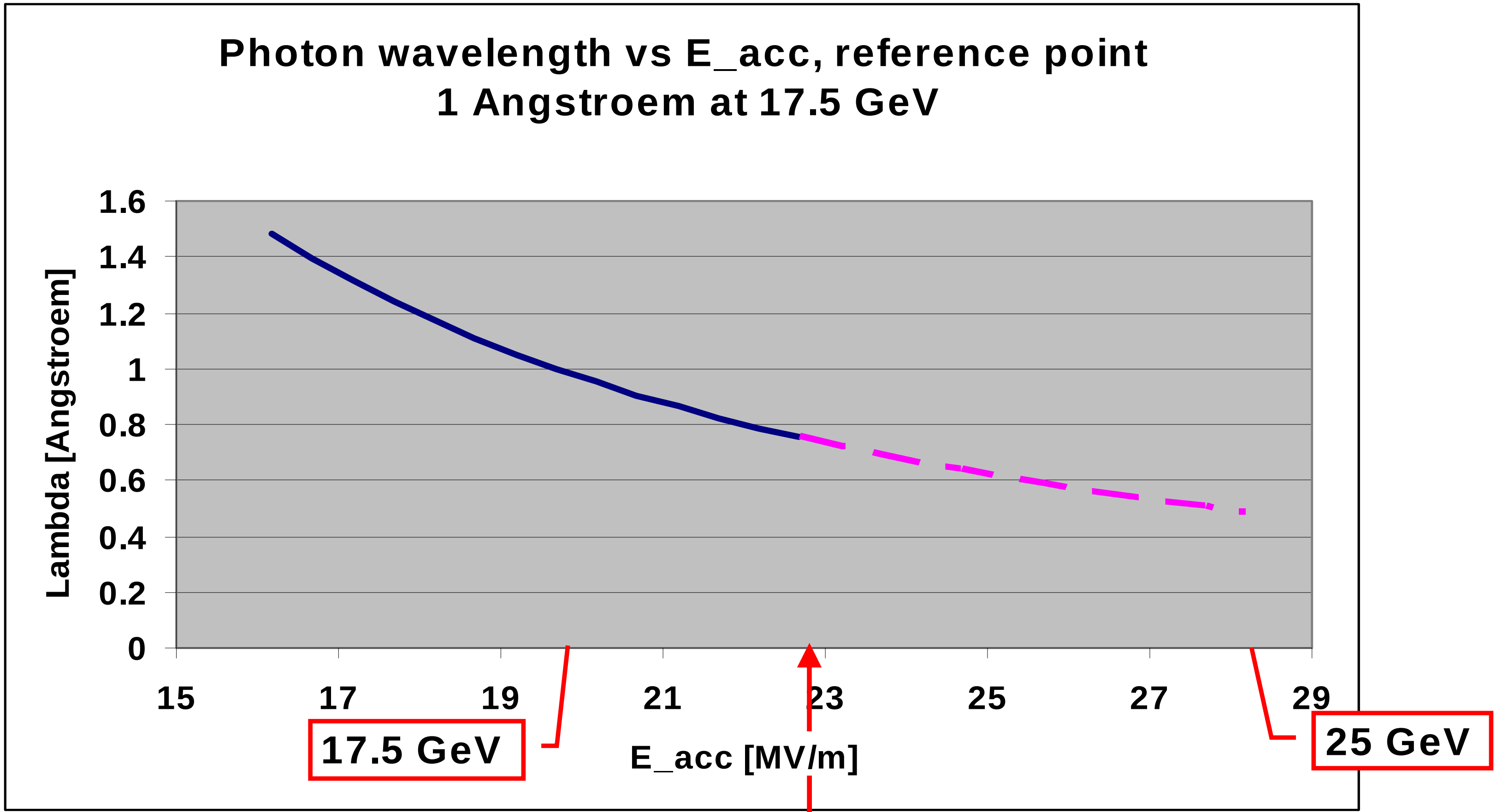
- DESY will build the XFEL, therefore
  - The focus will be necessarily on the industrialization
    - Reliable gradient performance for XFEL
      - System is laid out for 28 MV/m
      - Plus operational overhead: 30 MV/m
      - Electropolishing is baseline technology
    - Training of companies
    - Long-time experience of SRF technology
      - Module test stand / TTF
    - This is true for all subsystems: Cavities, couplers, tuners…
  - In addition ILC will profit from
    - Module 6 (35 MV/m)
    - Experience with electropolishing and cleaning on multi-cell cavities
    - Design for other shapes (Jacek)
    - Cost reduction by large grain ingots (if successful)
  - Things, which DESY will not do at this point in time:
    - Build other cavity shapes
    - Other fabrication techniques (only in European CARE program)
    - Superstructures
    - Major changes in cryostat design

# Accelerator schematic layout




| Main linac | |
|---|---|
| Beam energy | 20 GeV |
| acc gradient | 22.9 MV/m |
| Bunch spacing | 200 ns |
| beam current | 5 mA |
| power→beam p. klystron | 3.8 MW |
| incl. 10% + 15% overhead | 4.8 MW |
| matched $Q_{ext}$ | $4.6 \cdot 10^6$ |
| RF pulse | 1.37 ms |
| Beam pulse | 0.65 ms |
| # bunches p. pulse | 3250 |
| Rep. rate | 10 Hz |
| Av. Beam power | 650 kW |

# Wavelength vs. acc gradient




**Nominal linac energy 20 GeV, includes $^{57}Fe$ line @ 0.8Å**

**Expected better cavity performance permits higher energy/smaller wavelength**

# Cavity Design Options

- Established baseline parameters
  - Frequency: 1.3 GHz
  - Operating temperature: 2K
    - Maybe minor changes
- Parameters under discussion
  - Gradient
    - XFEL: 28 MV/m
    - TESLA-500: 25 MV/m
    - TESLA-800: 35 MV/m
    - ILC: ???
      - Cost optimum is between 30-40 MV/m
        - » Depends on your cost model….
  - Cavity cell shape for ILC is an option
    - Increase $E_{peak}/E_{acc}$ :
      - field emission under control !?
    - Reduce $B_{peak}/E_{acc}$:
      - magnetic surface field limit achieved !?
      - This would increase the operating gradient
    - Very good summaries by J. Sekutowicz:
      - http://lcdev.kek.jp/ILCWS/Talks/13wg5-05-Shape_Sekutowicz.pdf
      - http://www.slac.stanford.edu/grp/ara/structures_meeting/JSekutowicz.pdf
  - Number of cells per accelerating structure
    - Superstructure

# Cavity Design

- Frequency choice
  - Lower frequency better for
    - RF losses (BCS surface resistance)
    - Lower wakefields
  - 1.3 GHz klystrons were available
- RF Layout
  - Number of cells determined by maximum cell-to-cell coupling $k_{cc}$ (field flatness)
  - Low $E_{peak}/E_{acc}$ (Field emission)
  - End cells asymmetric
    - Avoid trapping of TE121 higher order mode
    - Keep TM010 and first two dipole bands mode flat

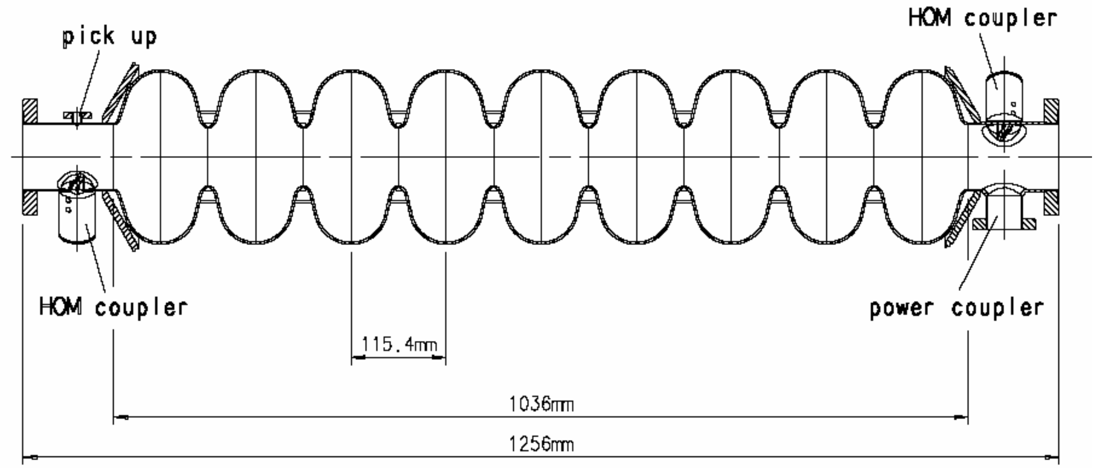
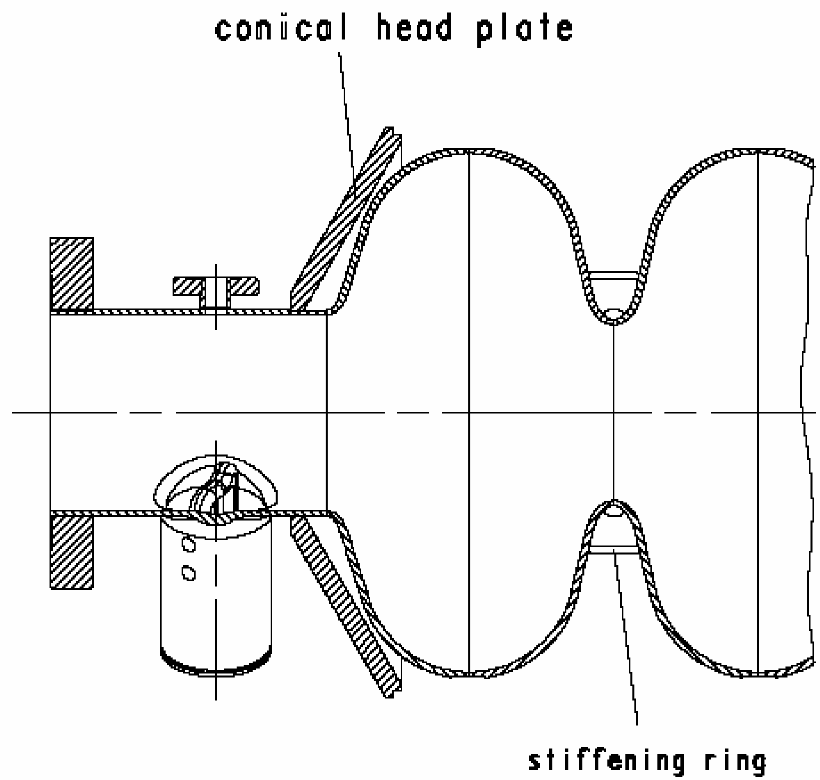
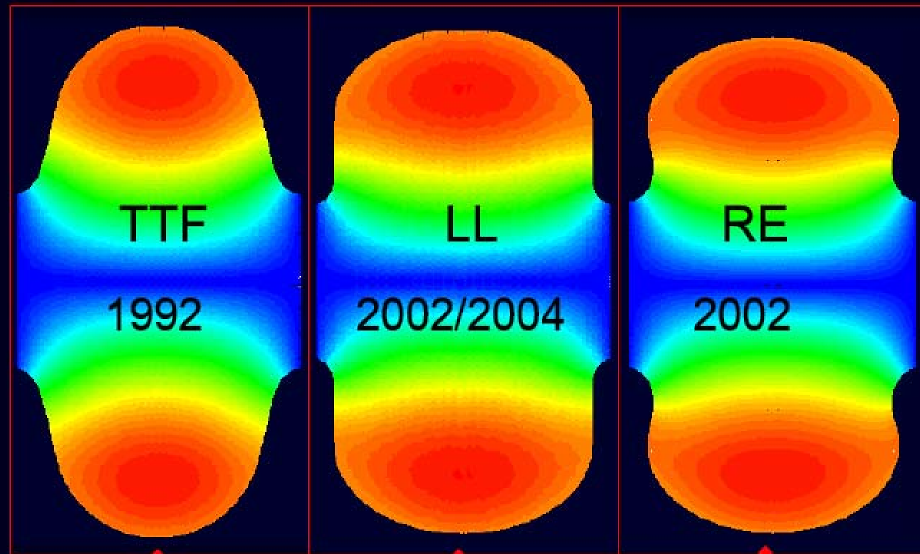


Figure 2.1.3: *Side view of the 9-cell cavity with the main power coupler port and two higher-order mode couplers.*



# 1. Introduction: Evolution of the elliptical cavities cont.

## Example: 1.3 GHz inner cells for TESLA and ILC

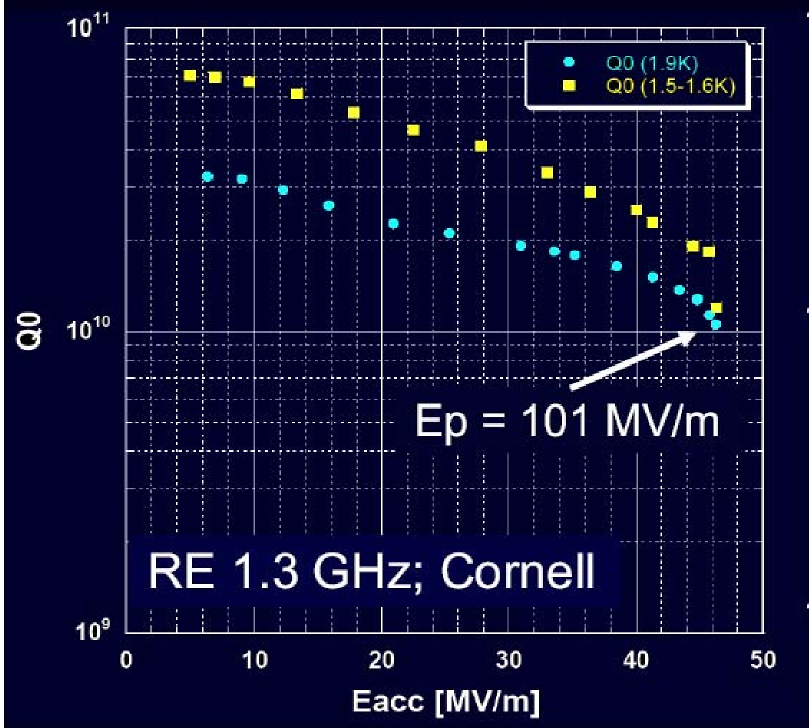


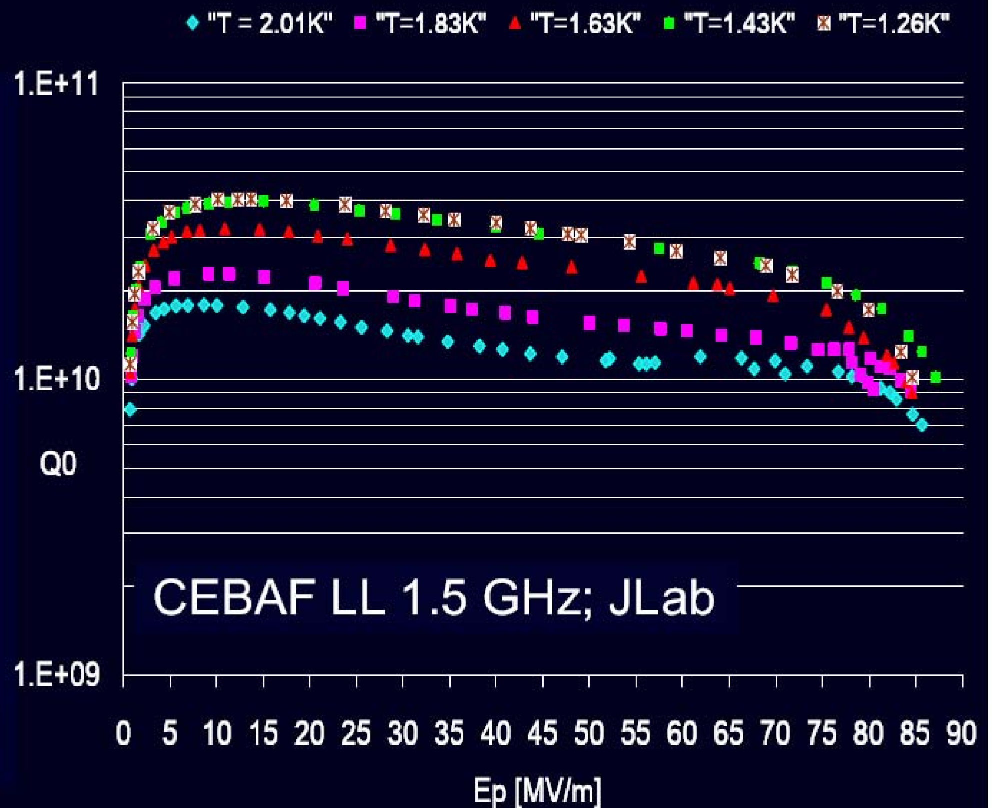

| | | | | | |
|---|---|---|---|---|---|
| $r_{irisb}$ | [mm] | 35 | 30 | 33 | |
| $k_{cc}$ | [%] | 1.9 | 1.52 | 1.8 | field flatness |
| $E_{peak}/E_{acc}$ | - | 1.98 | 2.36 | 2.21 | max gradient (E limit) |
| $B_{peak}/E_{acc}$ | [mT/(MV/m)] | 4.15 | 3.61 | 3.76 | max gradient (B limit) |
| R/Q | [Ω] | 113.8 | 133.7 | 126.8 | stored energy |
| G | [Ω] | 271 | 284 | 277 | dissipation |
| R/Q*G | [Ω*Ω] | 30840 | 37970 | 35123 | dissipation (Cryo limit) |

# 2. Low Loss cavity: Fundamental Mode, cont.

Single-cells!!!

$E_{peak}/E_{acc} = 2.36 \longrightarrow E_{peak} = 83$ MV/m at Eacc = 35 MV/m



# 2. Low Loss cavity: Fundamental Mode, Multi-cell parameters

| | | LL | TTF |
|---|---|---|---|
| Type | - | symmetric | asymmetric |
| $f_\pi$ | [MHz] | 1300.0 | 1300.0 |
| Number of cells, Nc | - | 9 | 9 |
| $k_{cc}$ | [%] | 1.52 | 1.9 |
| $E_{peak}/E_{acc}$ | - | 2.36 | 1.98 |
| $B_{peak}/E_{acc}$ | [mT/(MV/m)] | 3.61 | 4.15 |
| R/Q | [Ω] | 1166.5 | 1012 |
| G | [Ω] | 284.8 | 271 |
| (R/Q*G) / Nc | [Ω*Ω] | 36913 | 30472 |

# 5. Summary and the next steps

What is good about this structure ?

- Lower cryogenic loss by ~20% (as compared to TTF structure).
- Shorter rise time by 13% due to higher (R/Q) (as compared to TTF structure).
- Less sensitive to microphonics due to higher (R/Q) and thus lower Qext.
- Less stored energy by 13%.
- $B_{peak}/E_{acc}$ lower.

What is critical for this structure ?

- Higher $E_{peak}/E_{acc}$ = 2.36, (TTF structure 2).
- Weaker cell-to-cell coupling $k_{cc}$= 1.52% (TTF structure 1.9% ).
- HOM loss factors are higher: $k_{\perp}$ by 65% , $k_{\|}$ by 18 %.

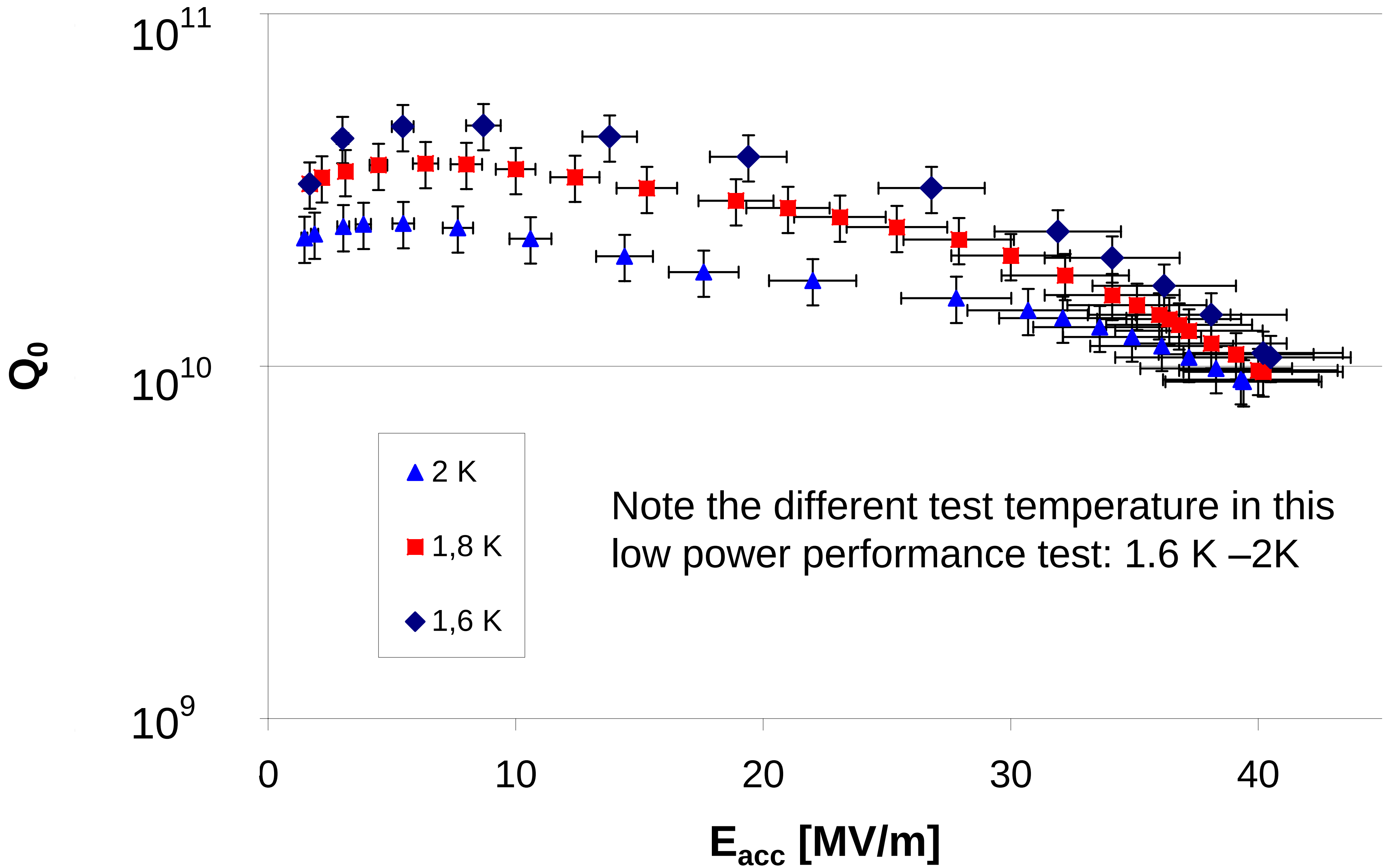
Open questions:

- Vibrations ?
- Preparation and cleaning ?

# Review on Tests for TTF Multi-Cell Cavities

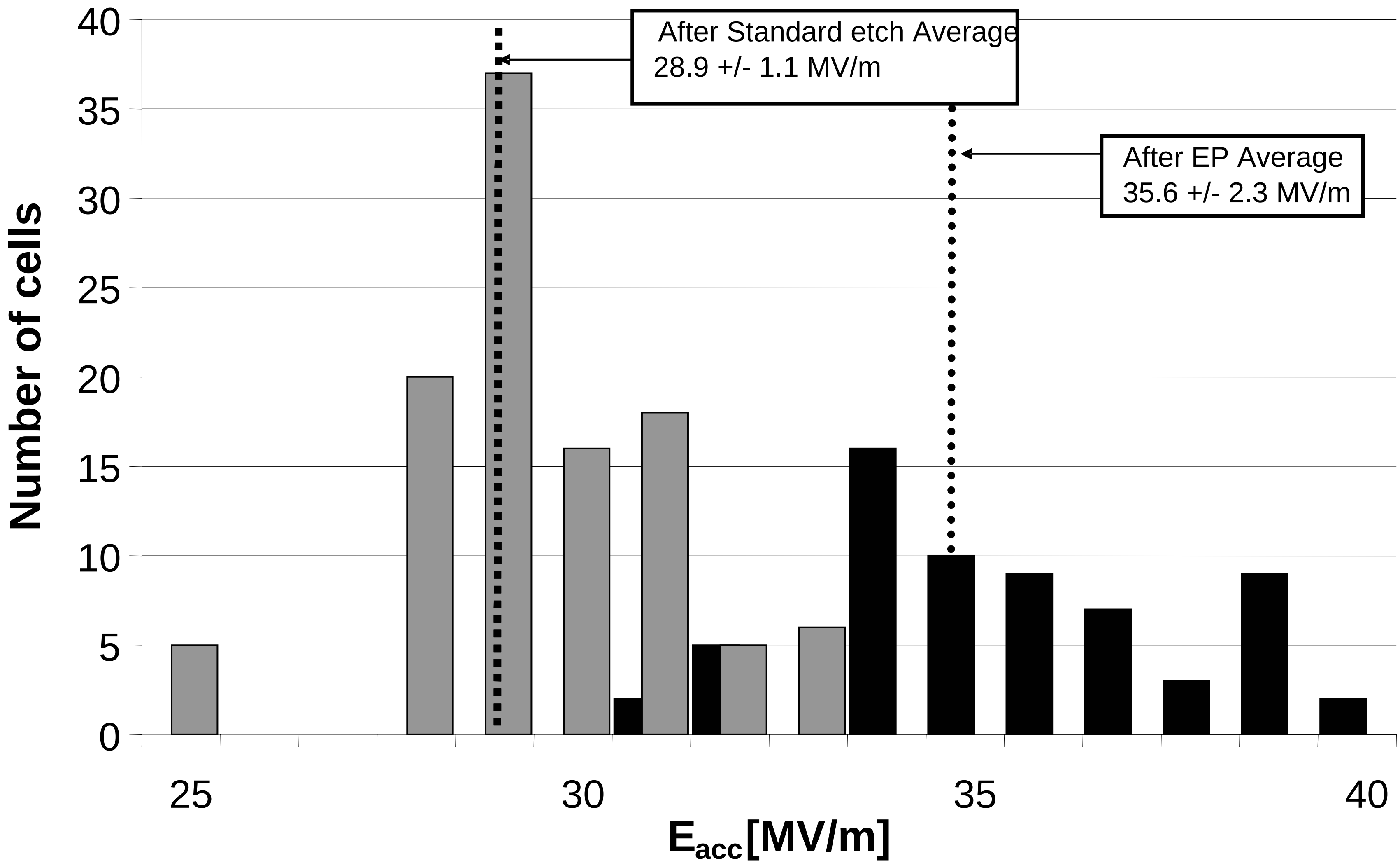
- Surface preparation is critical
  - Electropolishing (EP) is needed for high gradients
    - Some statistics available
    - Proof-of-principle: One EP cavity in the accelerator reached 35 MV/m!
  - Cleaning and assembly is critical
    - Risk of particle contamination
    - Causes field emission
- Integration into accelerator modules needs to be done carefully
  - Avoid contaminations
    - More reliable cleaning needed: 2nd High Pressure Rinsing System being designed
  - Quality control measures for all components and their assembly procedures need improvement

# CW Test: AC70: EP at DESY



# Comparison of EP to Standard Etch

## (Results from the KEK-DESY Collaboration)

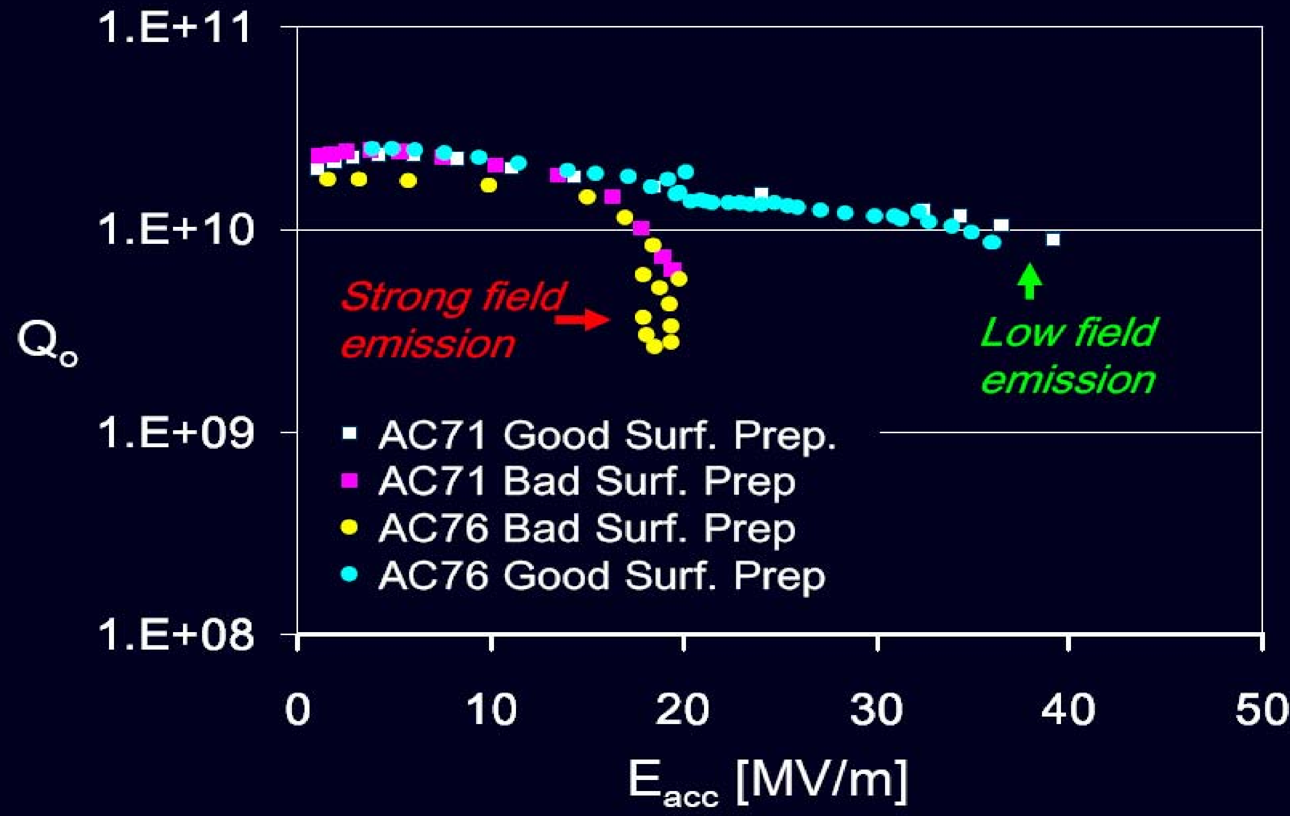



- EP offers systematically higher gradient than standard etch (single cell results from mode analysis of multi-cells)

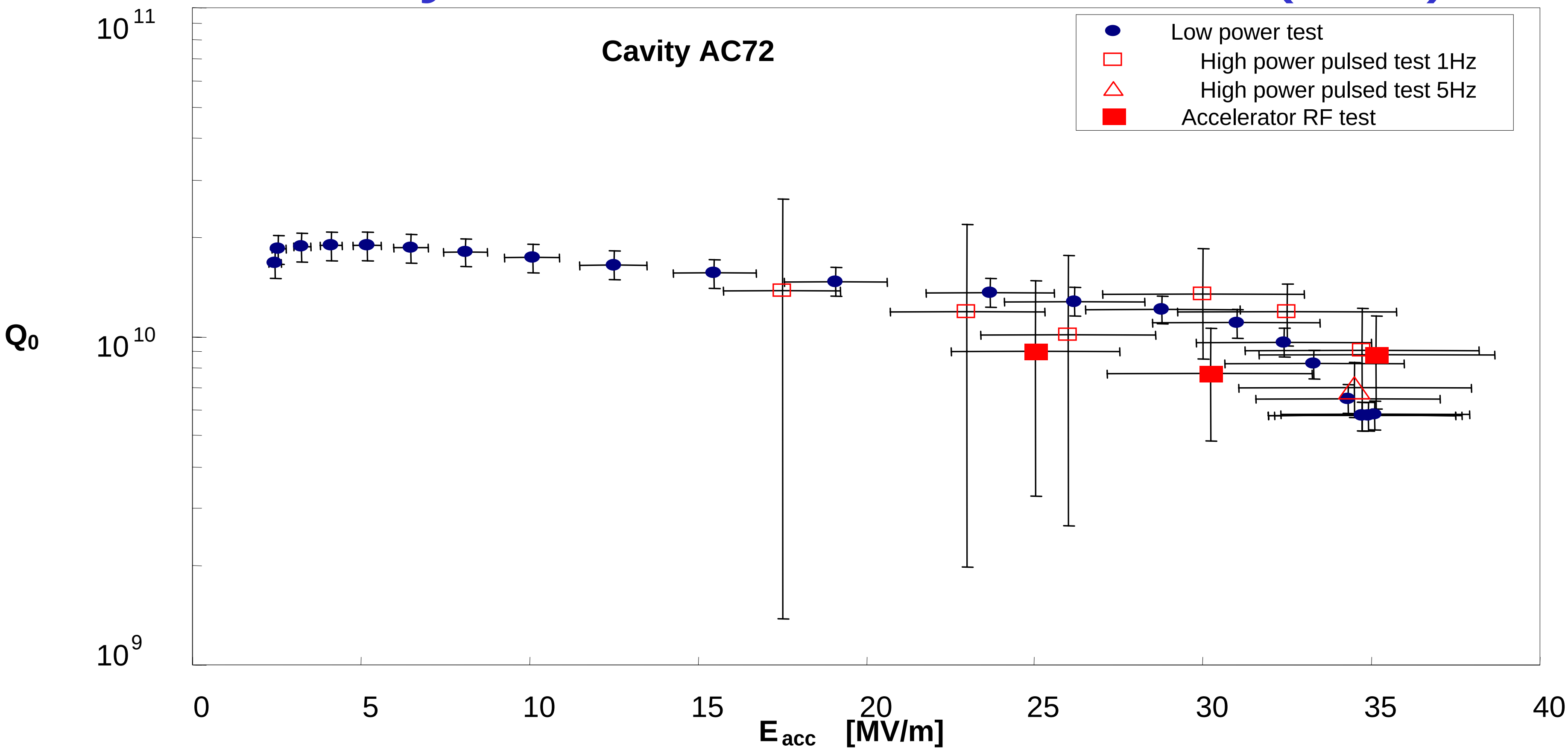
# 1. Introduction: Criteria cont.

Avoiding field emission is an ongoing struggle !

Some examples: 2002/2005



# 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

# Complete Accelerator Modules - Tests in TTF

- Gradient performance
- HOM measurements
  - Use as BPM
- …

# Performance of Accelerator Module 5

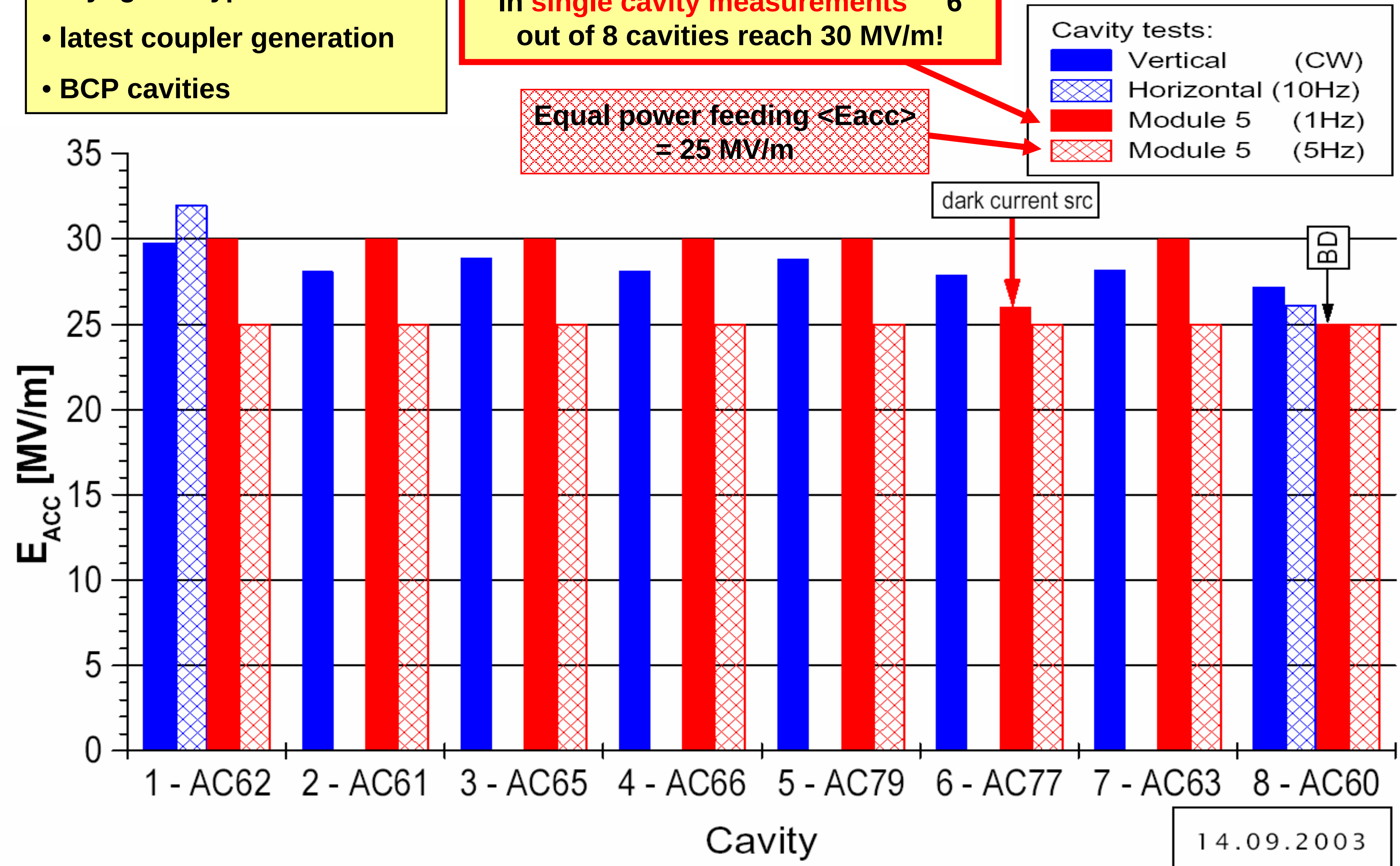
From H. Weise/ D. Kostin

**A State-of-the-art module**

- cryogenic type III
- latest coupler generation
- BCP cavities

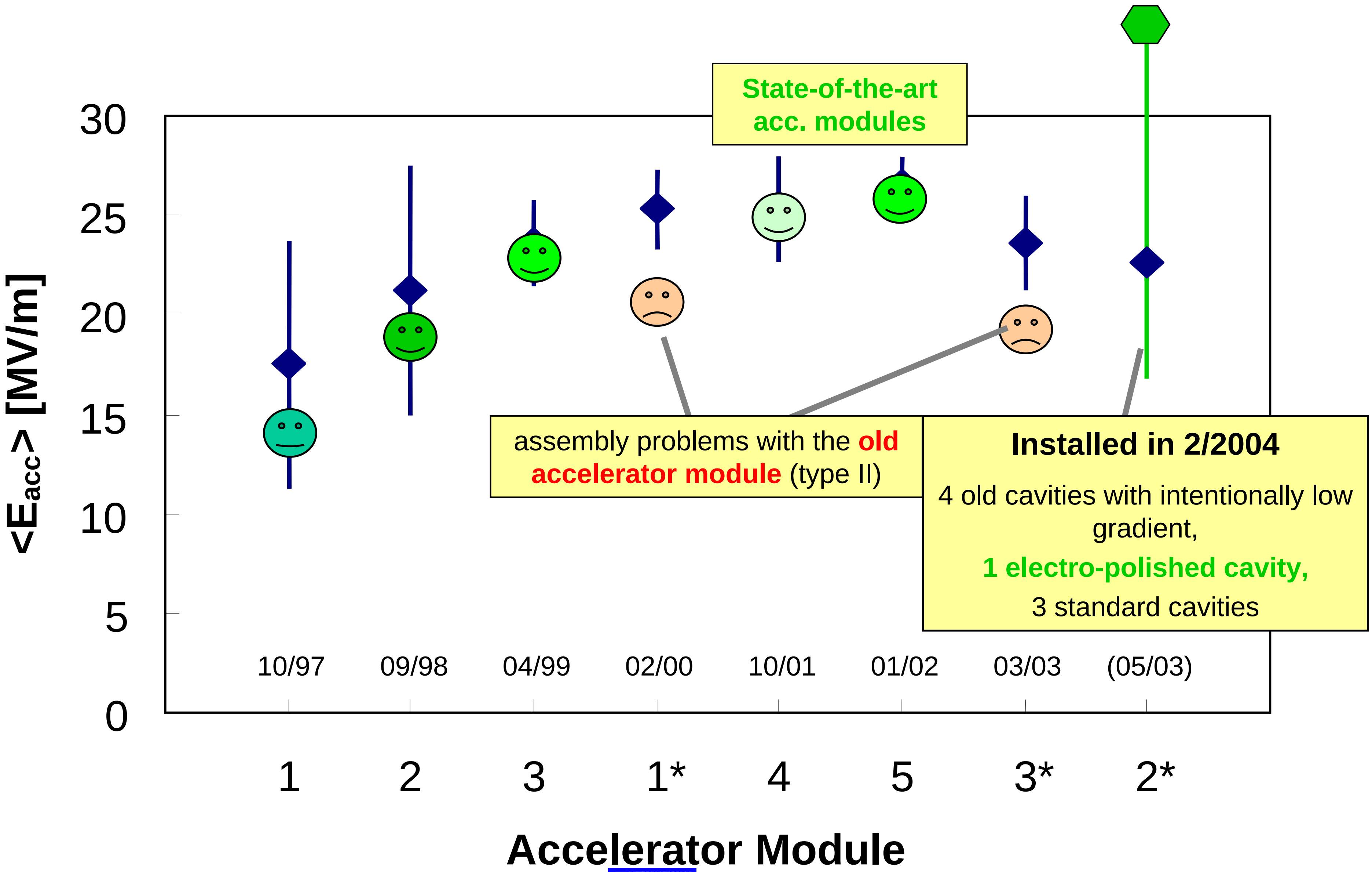
In single cavity measurements 6 out of 8 cavities reach 30 MV/m!

Equal power feeding <Eacc> = 25 MV/m



# Gradients of Accelerator Modules

From H. Weise



# Summary of Available Gradients today

- For TTF shape multi-cells:
  - Individual cavities with electropolishing
    - Continuous wave tests: up to 40 MV/m
    - Accelerator: Proof-of-Principle 35 MV/m
  - Full modules: 25 MV/m (etched cavities)
- But:
  - More reproducibility needed for cavity preparation
    - Still a large scatter in results
    - most of this is due to field emission
  - One of the lessons learned:
    - High pressure rinsing is critical
    - We will build a second HPR system to have a backup system

# Open Issues: Surface Preparation and Module Integration

- Basic research on EP and 'In-Situ' bakeout:
  - What are the fundamental limiting effects?
    - Measurements on superconducting properties of samples are needed
      - Some work has been done at Uni Hamburg (Casalbuoni, Steffen, Schmüser et al.), but programme discontinued
    - Tests on single-cells
      - Work ongoing in several labs (DESY: D. Reschke et al.)
  - Are there other cleaning techniques worth considering?
- Engineering
  - Module integration needs more quality control procedures
    - Esp. Field emission
  - Industrialisation of EP
    - Work on single-cells has started in Germany
    - In Japan Industry was always involved
  - Module assembly in industry
    - Industrial study is just being launched
  - These are of course major goals for the XFEL

# Example of Work on Auxiliaries: Frequency Tuner

- Tuner consists of 2 parts
  - Slow tuner
    - Allow for different thermal shrinkage
    - Correct slow drifts e.g. He pressure
    - Specification:
      - Range: 820 kHz
      - Resolution: 1 Hz /step
    - 2 basic types have been tested
      - Lateral (Saclay)
      - Coaxial (INFN, DESY)
  - Fast tuner
    - Compensate Lorentz-forces
      - df <= 1 kHz in 1 m
    - Piezoelectric

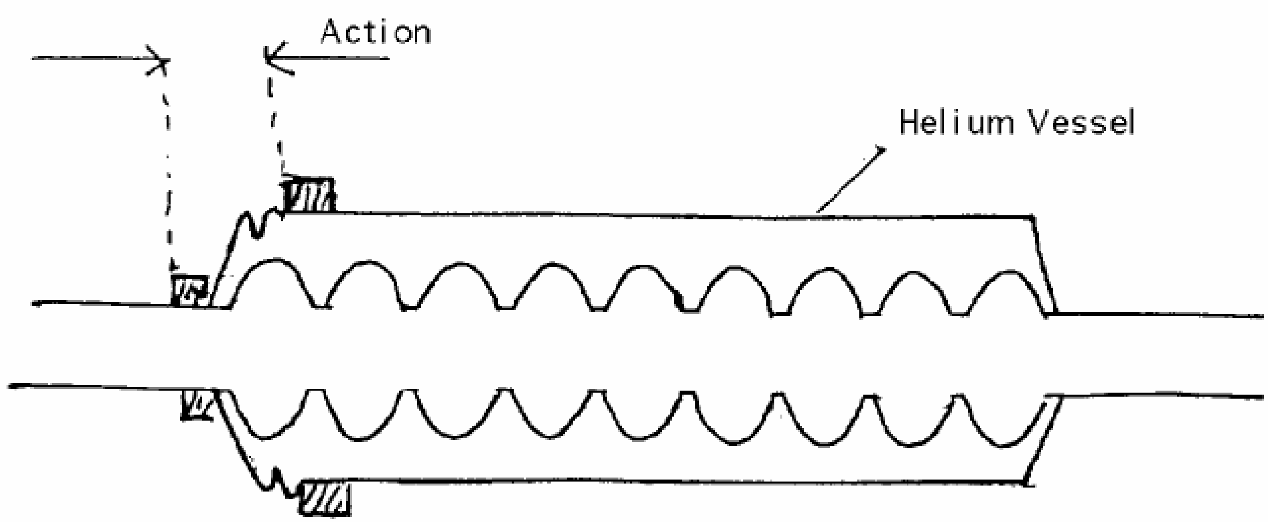
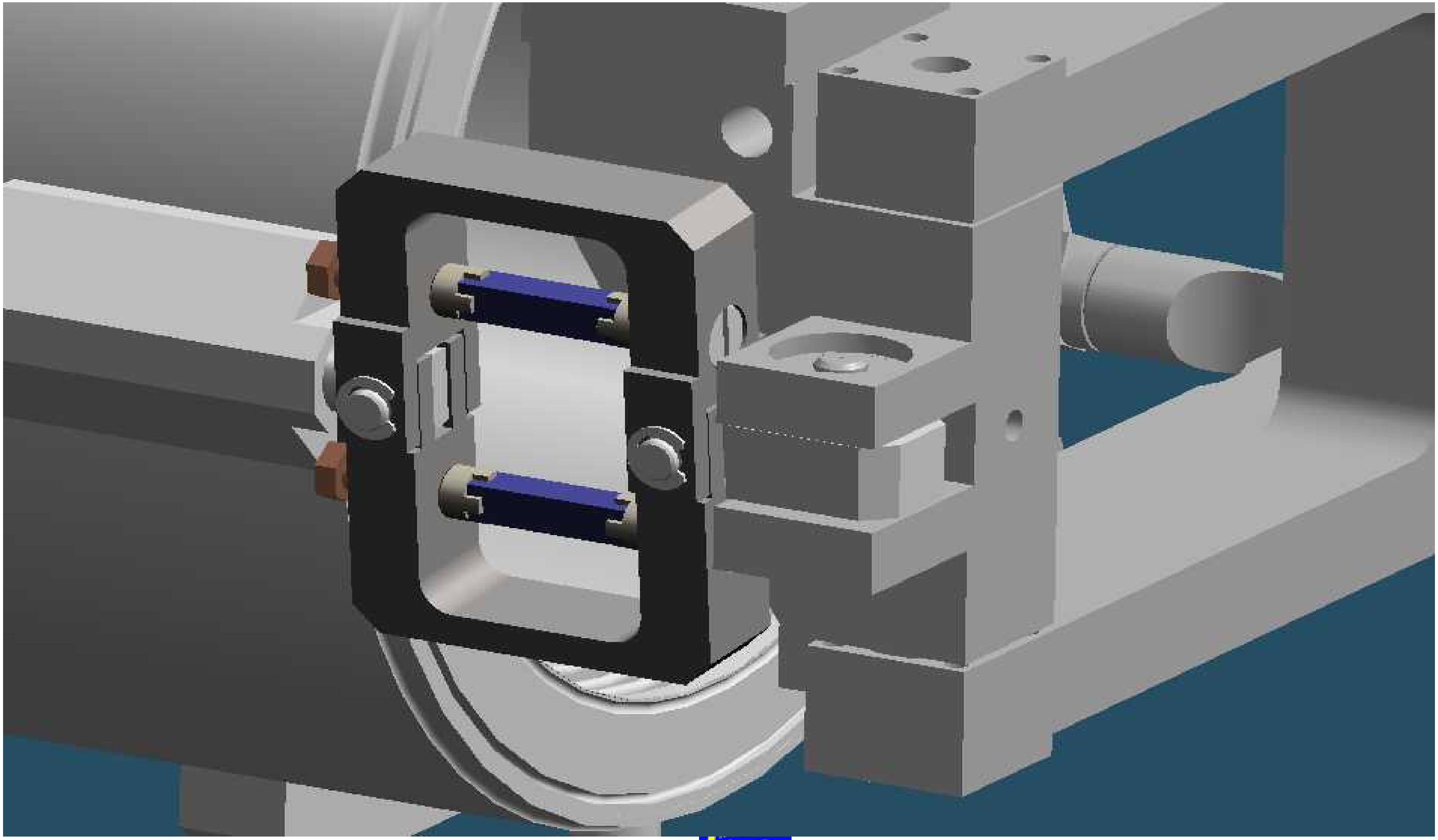



Figure 4.21: How the CTS is acting on the cavity length.

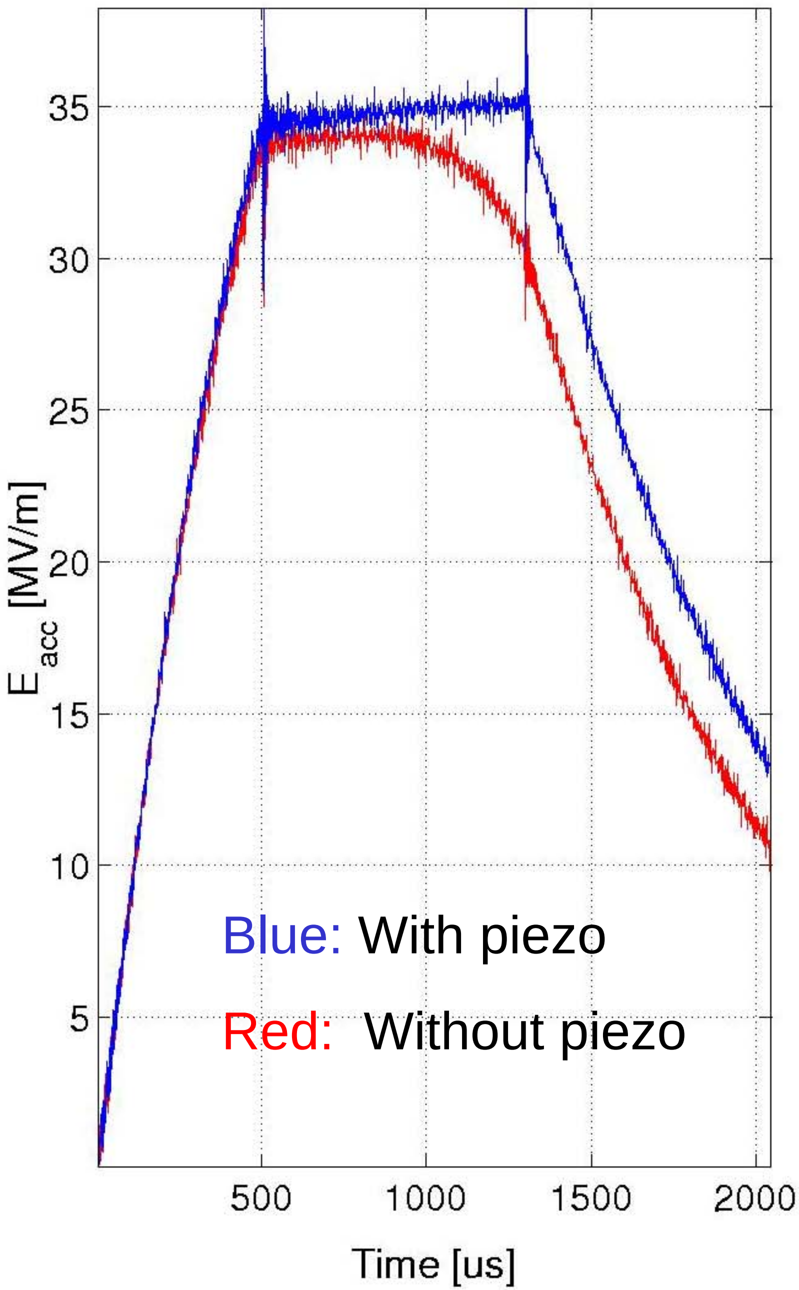
# Active Tuner

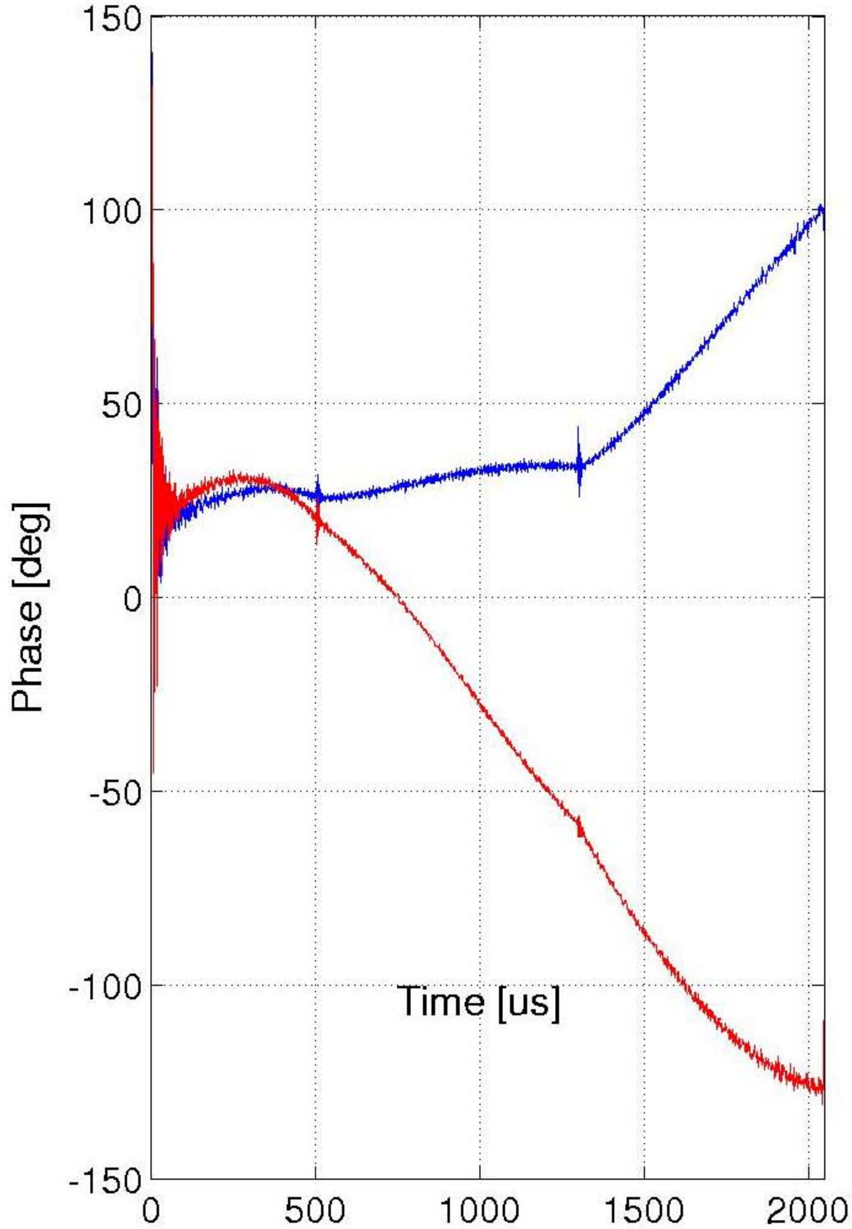
- Actively compensate the detuning of the cavity during the RF pulse by mechanical means to reduce power consumption
- Piezoelectric elements are suitable for this application (heavily used for fuel injection in car industry)
  - Magnetostrictive materials can be an option
- Proof-of-principle done
- A lot of engineering needed
  - Choice of tuner
  - Choice of Actuator
  - …

# Drawing of Piezoelectric Elements in the Tuning Mechanism



# RF Signals at 35 MV/m



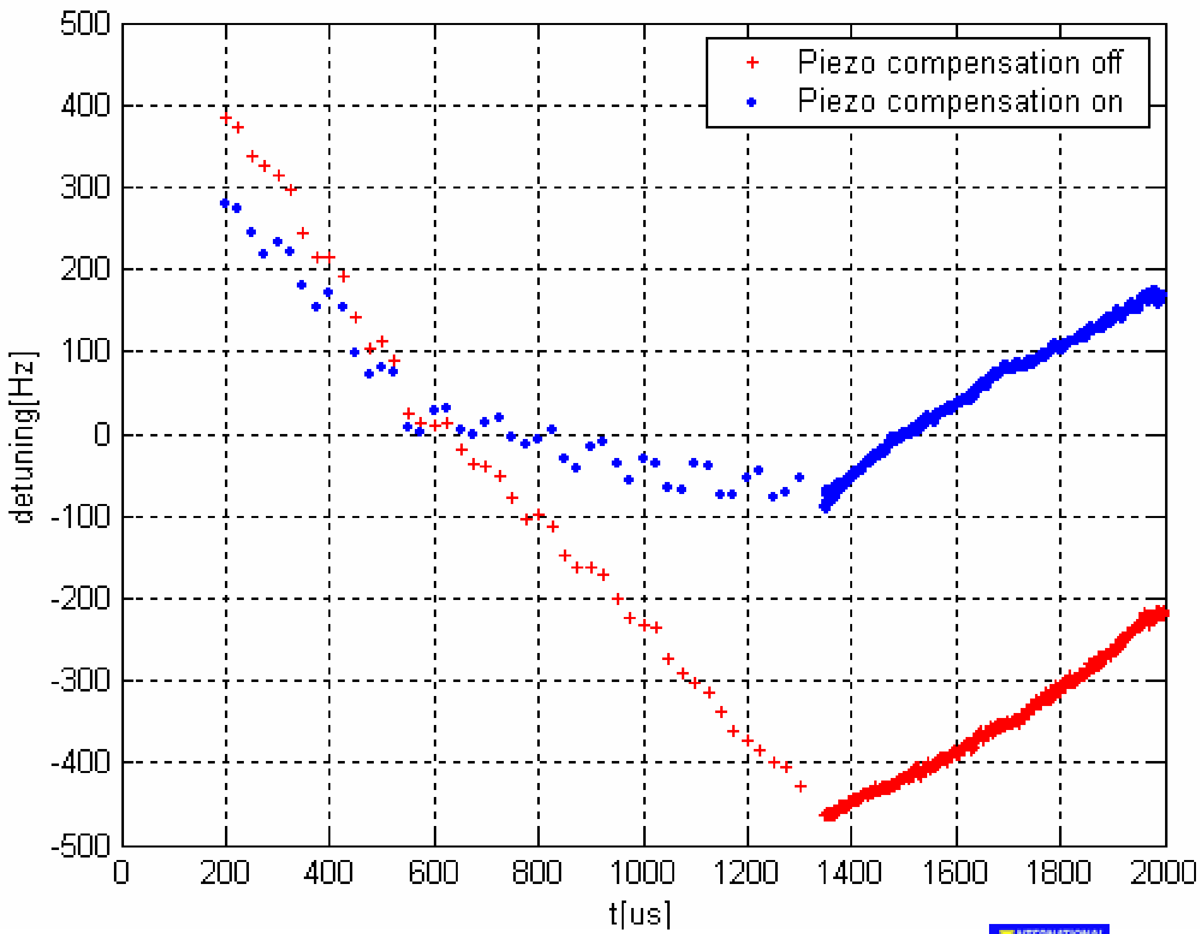



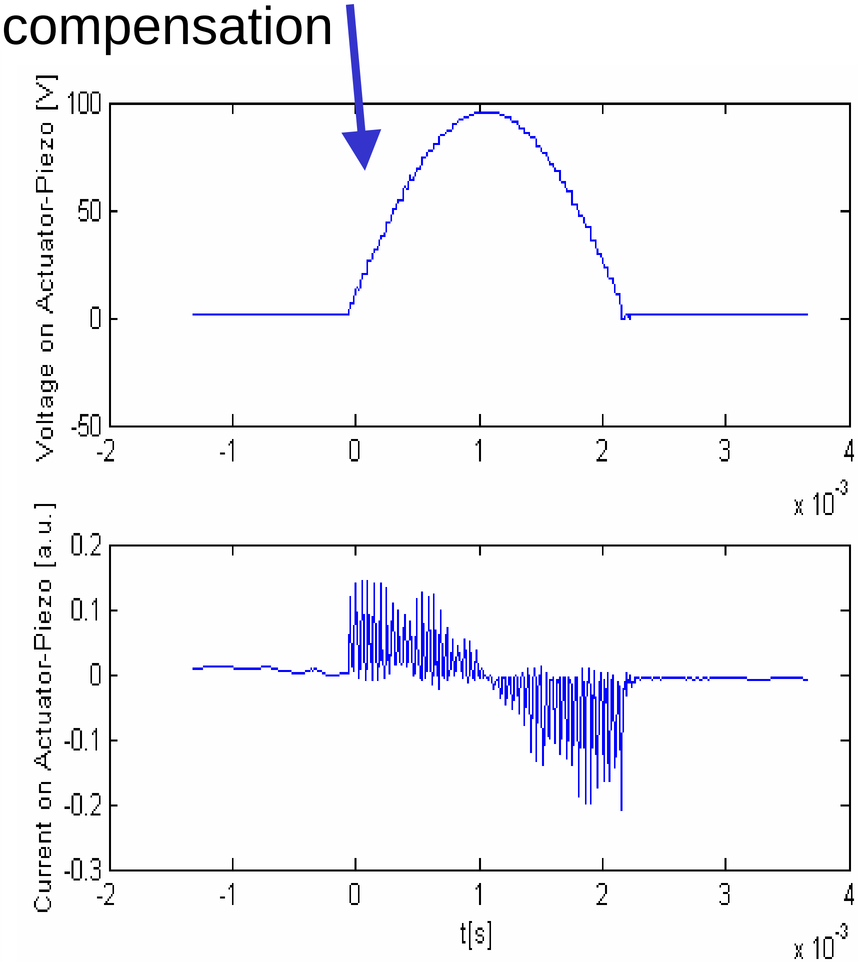
# Frequency stabilization during RF pulse using a piezoelectric tuner

Blue: With piezo

Red: Without piezo

Frequency detuning of 500 Hz compensated voltage pulse (~100 V) on the piezo. No resonant compensation

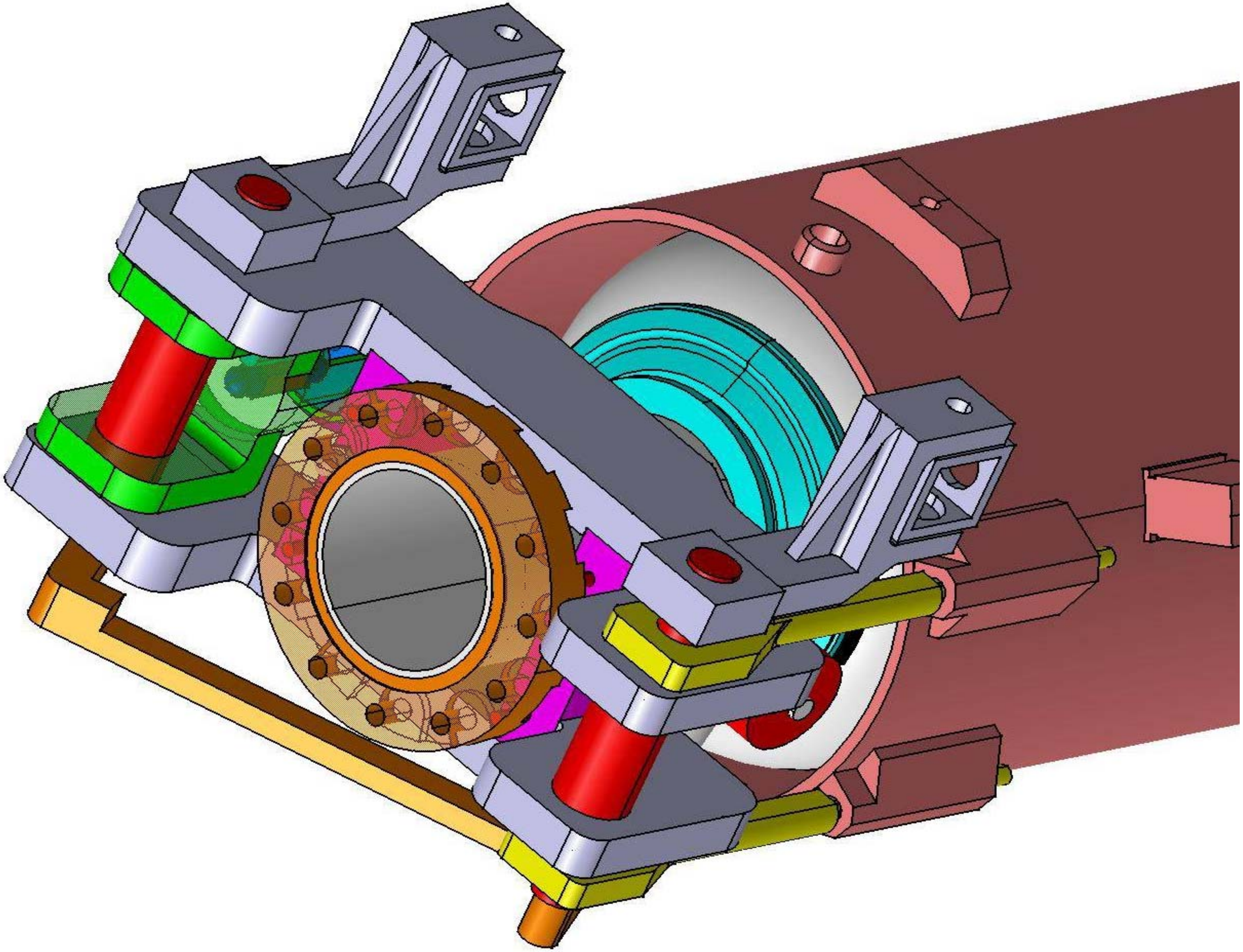


# New Saclay Tuner

- Design by P. Bosland
- More compact design possible
- Cavity should be pre-tuned so that the tuner is not pushing
- Piezo integrated
- Available by the mid of the year for first tests

# New Saclay Tuner 2



# Summary

- For the high gradient programme work is ongoing
  - Cavity shapes
    - Involved with design (Jacek)
      - Prototypes tested by the end of the year
  - Surface preparation
    - Proof-of-Principle: 35MV/m in the accelerator
    - Quality control needs improvement
      - High priority for XFEL
      - 2nd High pressure rinsing system as backup being designed
    - Basic research on samples/single-cells is needed for ILC
      - Superconducting properties of niobium
      - Other cleaning techniques
  - Module Integration
    - Quality control needs improvement
    - High priority for XFEL
  - Auxiliaries
    - A lot of engineering needed

# Thank you…

- … to Hans-Bernhard Peters, Jacek Sekutowicz and Hans Weise for their viewgraphs
- … and the TESLA Collaboration for the work that has been done to date

# References

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