S0S1 Taskforce: A Collection R&D Results

High-Gradient SC Cavities

Lutz Lilje

GDE

Outline

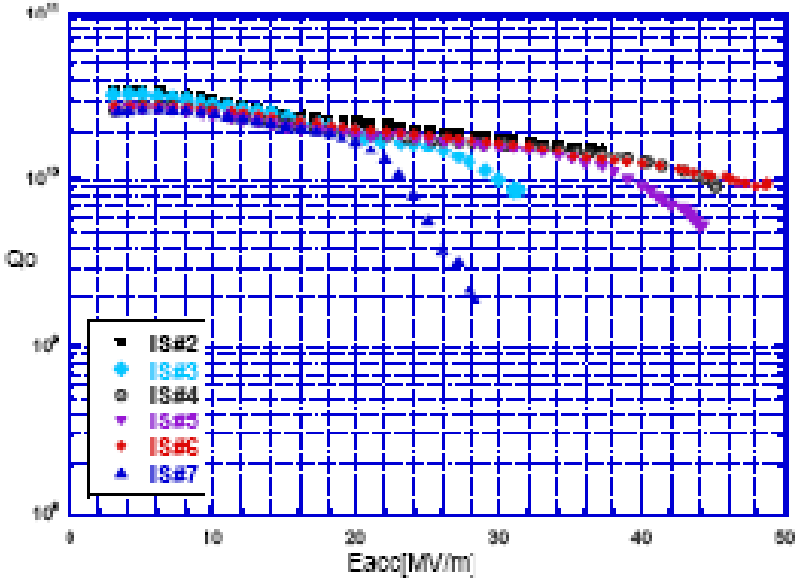
- S0S1 R&D Results
  - **S0**
    - Single-cells
    - Tight-loop
    - Production-like
  - **S1**
    - Recent tests on M6 and M7 at DESY
  - **Alternatives**
    - Material
    - Surface preparation
    - Cavity geometry

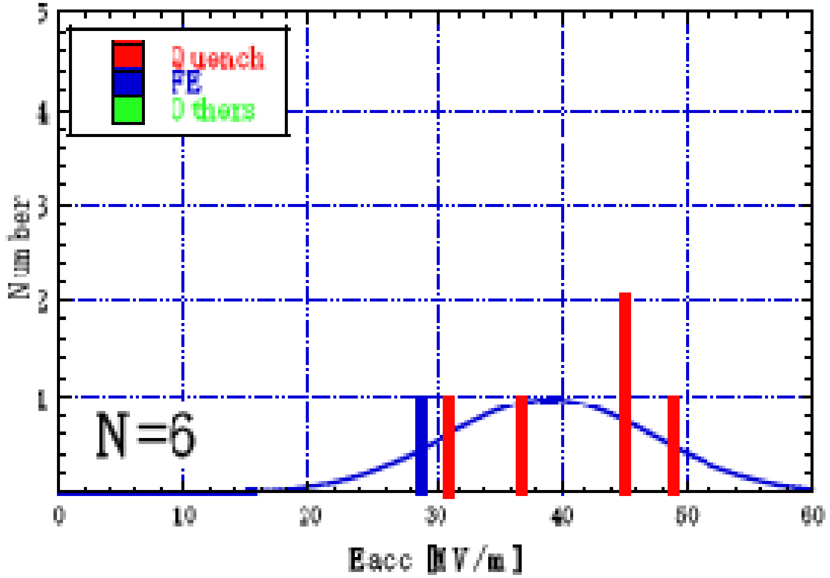
S0S1 'Tight-Loop': Improvement of the Cavity Preparation Process

- Basic assumption
  - **Preparation is the critical step**
- Main goal:
  - **Demonstrate 80% yield in first acceptance test, then 95% with second try**
- Tight-loop
  - **Test minor variations in the final surface preparation**
    - Conduct a dedicated single-cell program
    - Cavity exchange
    - Compare regional preparation setup performance
  - **Demonstrate multi-cell handling**
  - **Demonstrate optimized treatment in a second cycle**
- R&D results
  - **Single-cells**
    - Comparison of final preparation methods (mostly at KEK)
    - Yield already one strong candidate for these processes: 'fresh acid'
  - **Multi-cells**
    - First tight-loop experiments
    - Two candidate processes: Ultrasound degrease and H_2O_2

(A) CBP+CP+Anneal+EP(80μm) +HPR+Baking(120C*48hrs)

K. Saito et al.





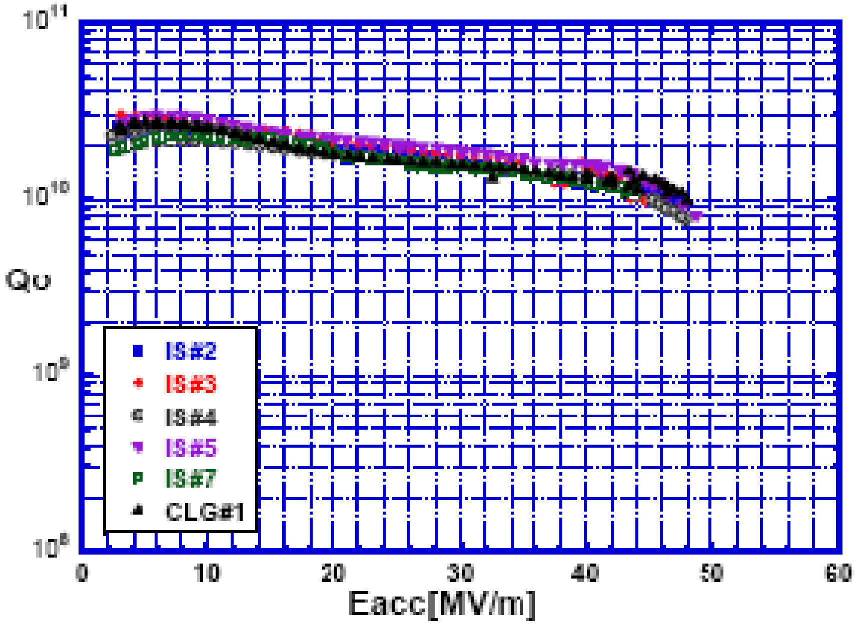
Ave. Eacc=39.1±8.2MV/m

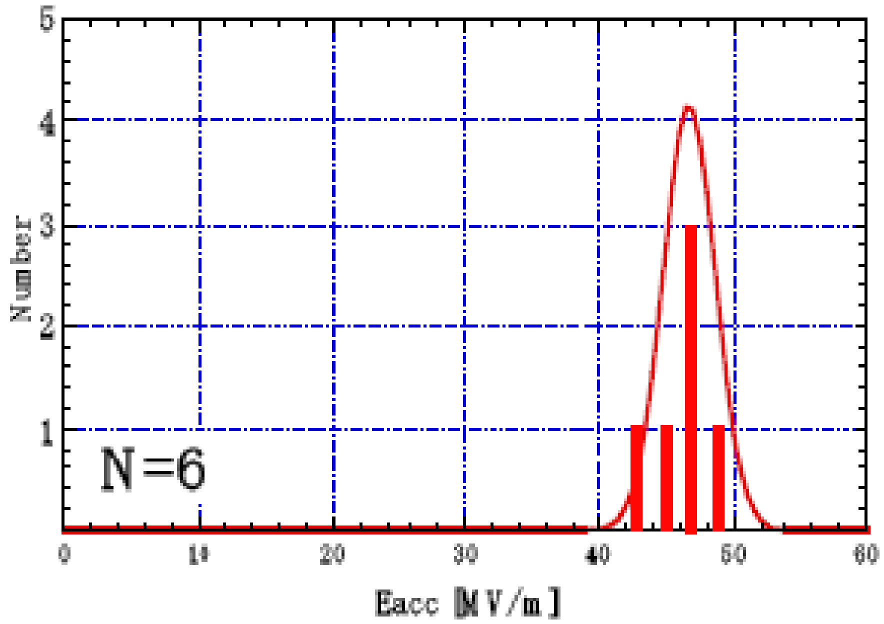
Scattering:20%, Acceptability@40MV/m(ACD):50%

		IS#2	IS#3	IS#4	IS#5	IS#6	IS#7
EP(80)	Eacc	36.90	31.40	45.10	44.20	48.80	28.30
	Qo	1.53e10	8.66e9	9.07e9	5.38e9	9.64e9	1.94e9

(D) +EP(20μm)+EP(3μm, fresh, closed) +HF* +HPR+Baking (120C*48hrs)

K. Saito et al.





Ave. Eacc=46.7±1.9MV/m

Scattering:4%, Acceptability@40MV/m(ACD):100%

		IS#2	IS#3	IS#4	IS#6	IS#7	CLG#1
+EP(20+3) +HF*	Eacc	47.07	44.67*	47.82	48.60*	43.93*	47.90*
	Qo	1.06e10	0.98e10	0.78e10	0.80e10	1.17e10	1.0e10

KEK: Single-Cell Comparison

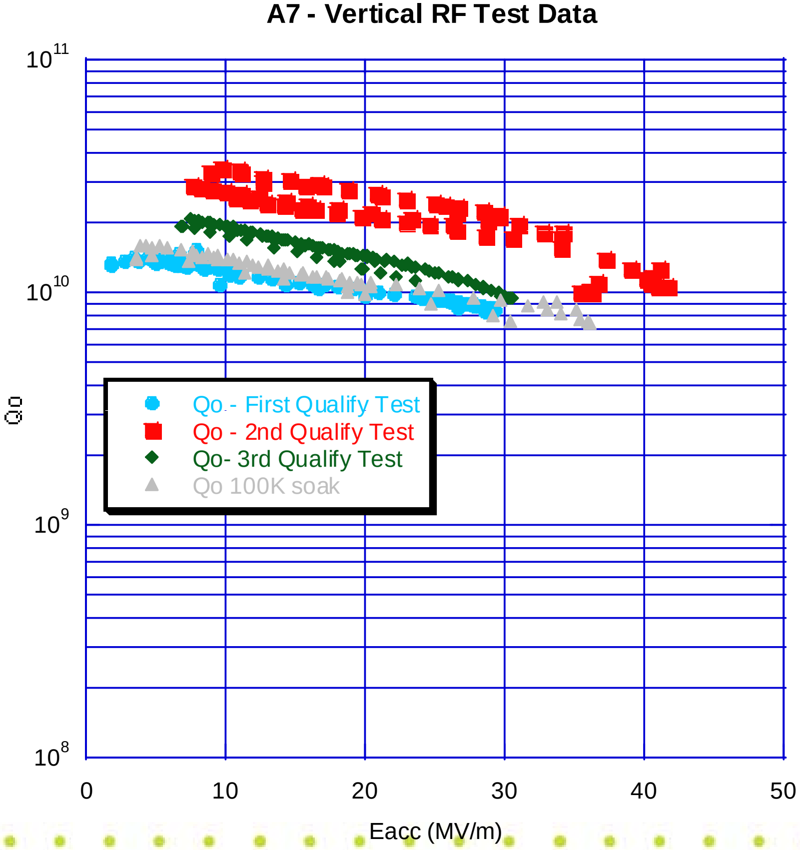
K. Saito et al.

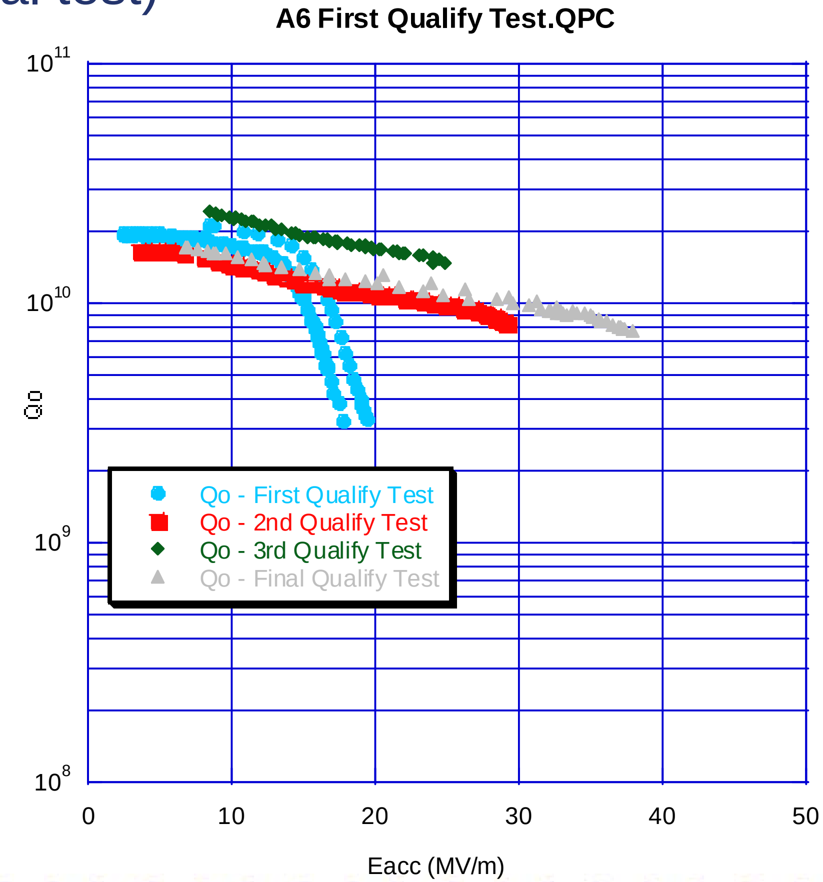
	Eacc,max [MV/m] / Qo @ Eacc,max									Emax average [MV/m]	Scatt. [%]	MP	Acceptability @ 40M V/m [%]
	IS#2	IS#3	IS#4	IS#5	IS#6	IS#7	IS#8	CLG#1	CLG#2				
CBP+CP+AN+EP(80)+HPR+ Bake	36.9	31.4	45.1	44.2	48.8	28.3				39.1 ± 8.2	21	Yes	50
	1.53E10	8.66E9	9.07E9	5.38E9	9.64E9	1.94E9							
CBP+CP+AN+ EP(80+3 fresh) +HPR+Bake		42.0	46.1	44.3	34.3	39.3			43.8	41.7 ± 4.4	11	Yes	67
		9.72E9	9.47E9	1.08E10	8.56E9	1.03E10			3.46E9				
CBP+CP+AN+ EP(40+3 fresh) +HPR+Bake	43.9						49.2*			46.6 ± 3.7	8	Yes	100
	9.47E9						4.33E9						
+EP(20)+HPR+Bake	47.2	52.2	52.9	31.1	48.9	46.5				46.4 ± 8.0	17	Yes	83
	5.98E9	1.51E10	5.23E9	5.21E9	7.56E9	9.03E9							
+EP(20+3 fresh)+HPR +HF+Bake	47.1	44.7	47.8		48.6	43.9		47.9		46.7 ± 1.9	4	Yes	100
	1.06E10	9.80E9	7.80E9		8.00E9	1.17E10		1.00E10					
+EP(20)+H_2O_2+HPR+ Bake	52.3			34.1	43.4	40.9				42.7 ± 6.0	18	Light	50
	1.09E10			1.37E10	1.39E10	3.01E9							
+EP(20)+Degreasing (US)+HPR+ Bake	50.1	52.2								51.2 ±1.5	2.9	Lights	100
	7.80E10	7.08E9											
Others Megasonic													

JLab Multi-Cells

J. Mammosser et al.

- Second candidate rinse
  - **Ultrasound degrease**
- All curves but one limited by quench
- Field emission in one test (A6 final test)



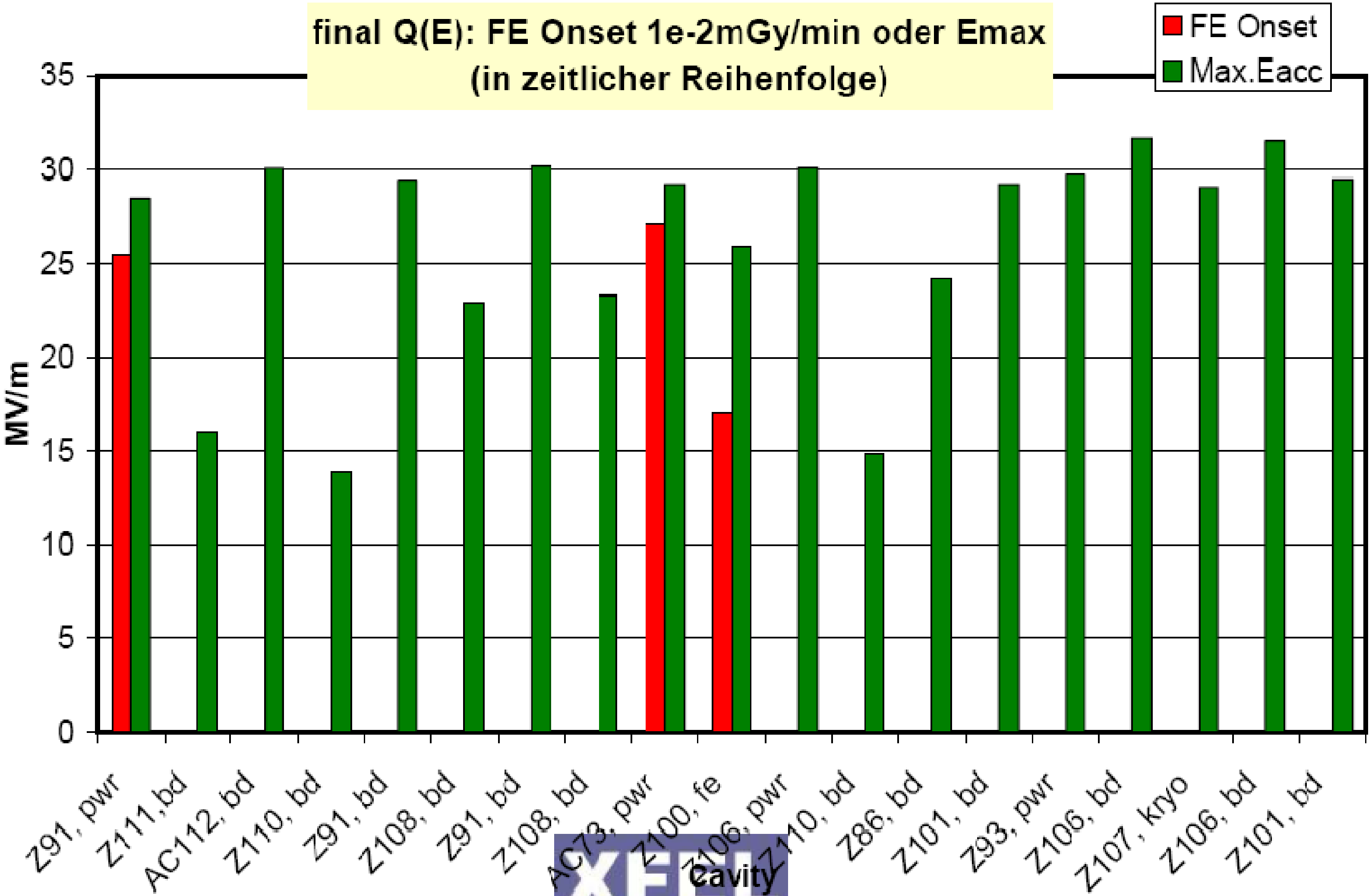


S0S1 'Production-like': Determine the Yield of the Full Production Chain

- Production-like tests
  - **Several cavities are treated in the same manner**
    - demonstrate full yield of the fabrication and preparation process
    - specify yield in more detail
    - includes cavity fabrication errors
      - New vendors will be tested
- R&D results
  - **Ongoing preparation work for the XFEL**
    - Update of the statistics
  - **KEK first try at new vendor (TESLA-like cavities)**
    - US develops also new vendor
  - **US results on a qualified vendor**
    - Both JLab and Cornell results

Development of Field Emission since Dec 06

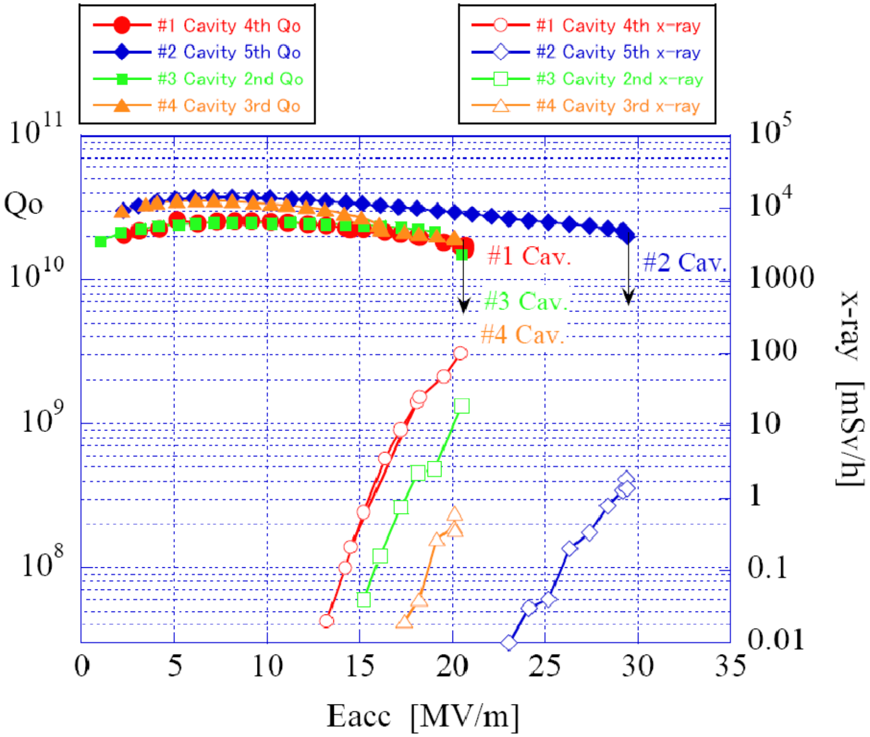
- Analysis of final Q(E)-results (if only one Q(E) was taken, this result is in both plots):



Final Performance in Vertical Tests

KEK TESLA-type Multi-Cells

(Kako, Noguchi)



Eacc,max

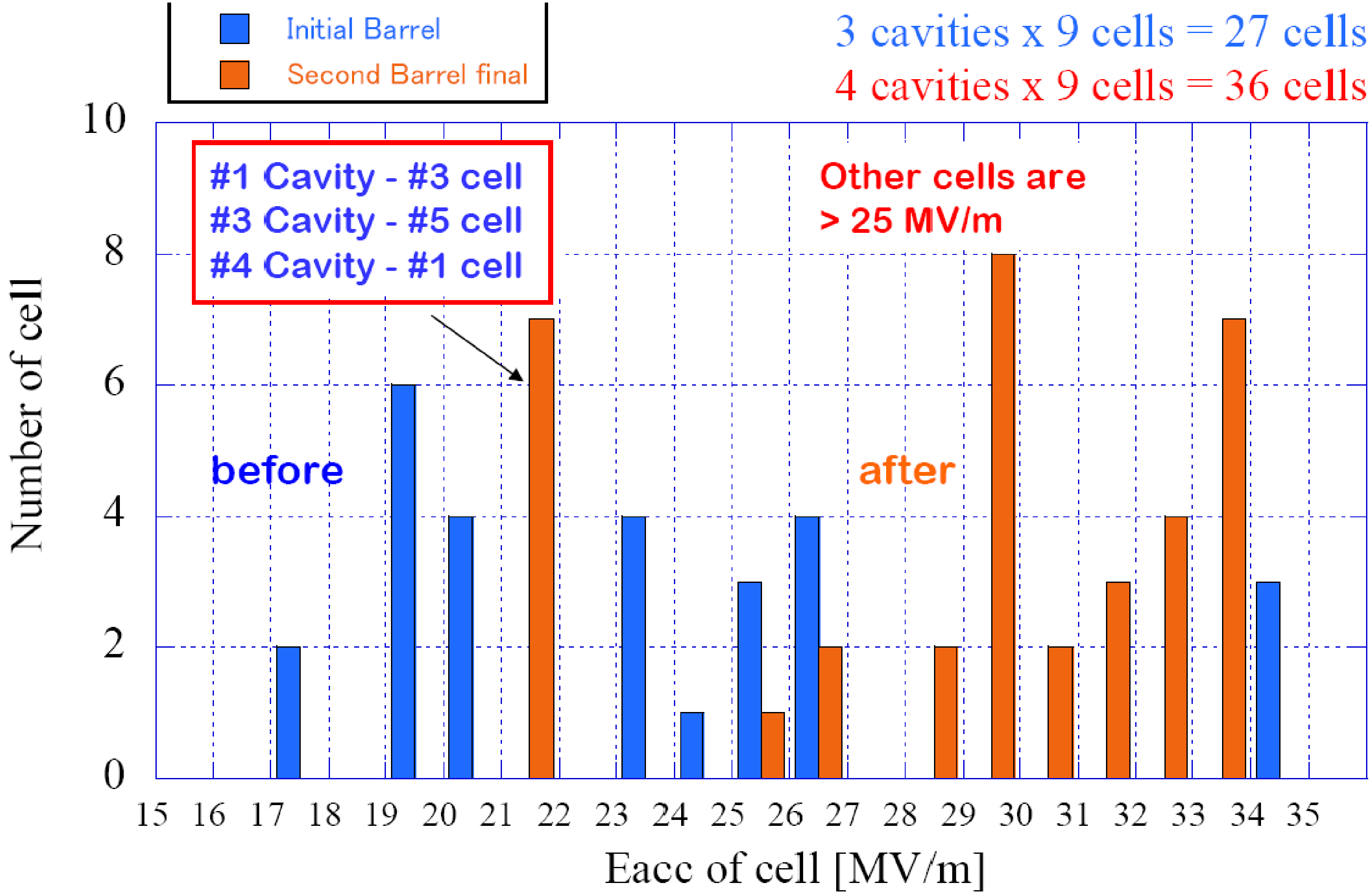
#1 20.8 MV/m
#2 29.4 MV/m
#3 20.5 MV/m
#4 20.2 MV/m

high Qo > 10^{10}

- New cavity vendor
- Surface treatment at ‘standard‘ company
- Field emission in first processing
- Only few cells are limited at low field ~21 MV/m
  - Similar to first 2 production runs at TTF few bad cells, but larger number gaussian distribution at higher gradient
- Best cavity at 29 MV/m!
  - 3rd alternative rinse: H_2O_2
- Tighter QC for future production runs will be implemented

Vertical Test Results, Eacc of cells

Before (total~250 μm), after 2nd BP (total~500 μm)

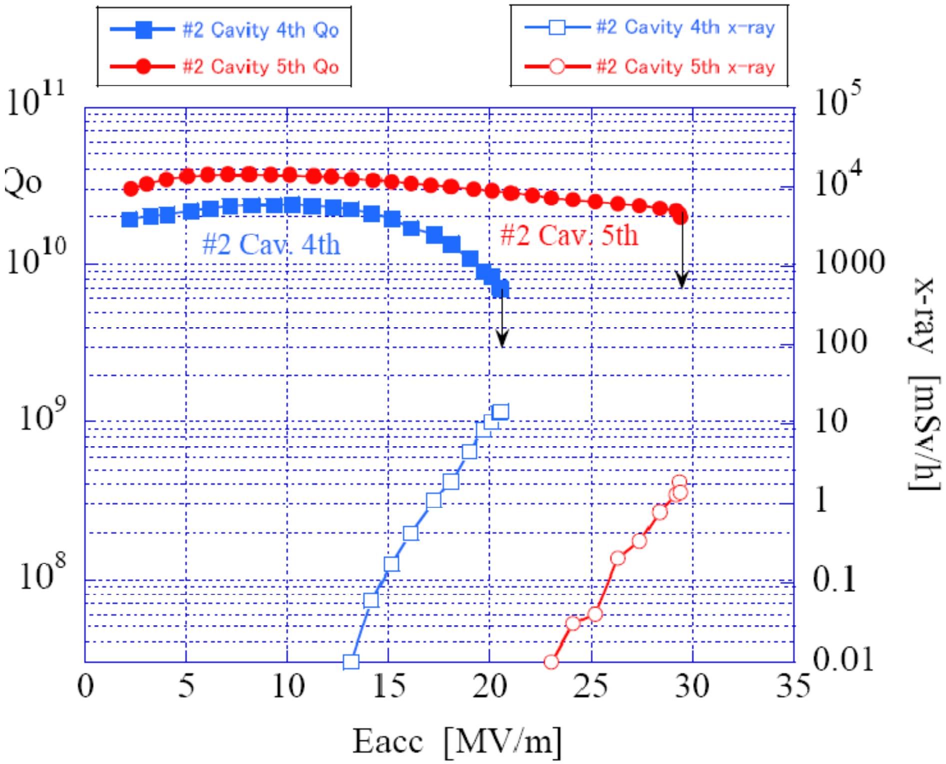


KEK TESLA-type: 3rd Alternative Rinse

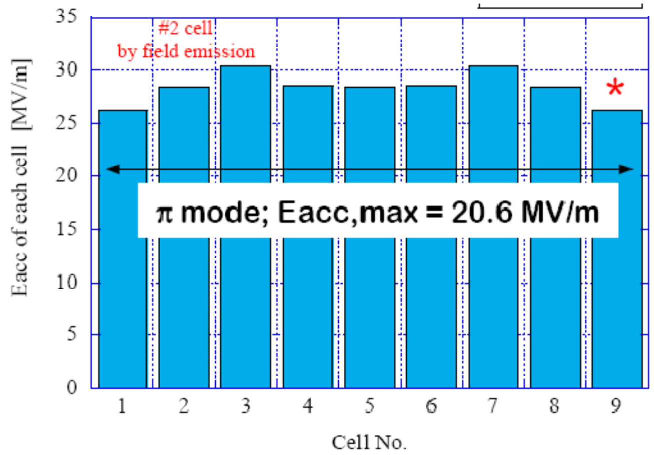
Vertical Test Results, #2 Cavity

#2 Cavity ; 4th and 5th Test

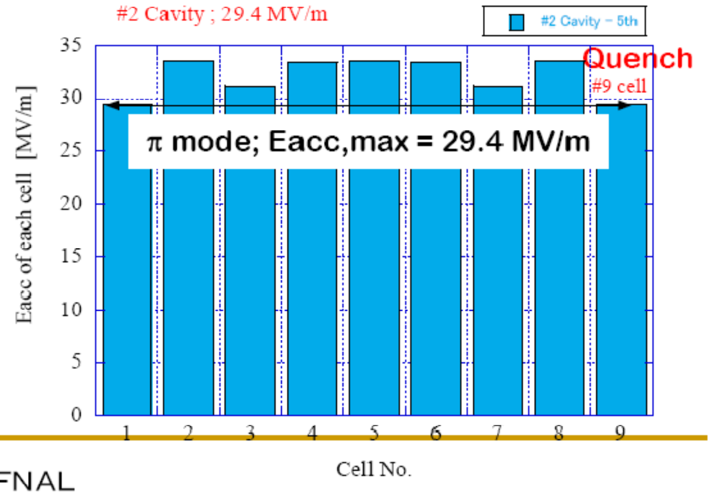
+ EP 20μm, H_2O_2 Rinse 1h, Hot Rinse 1h, HPR 16h



#2 Cav. 4th aft. 2nd Barrel Polishing



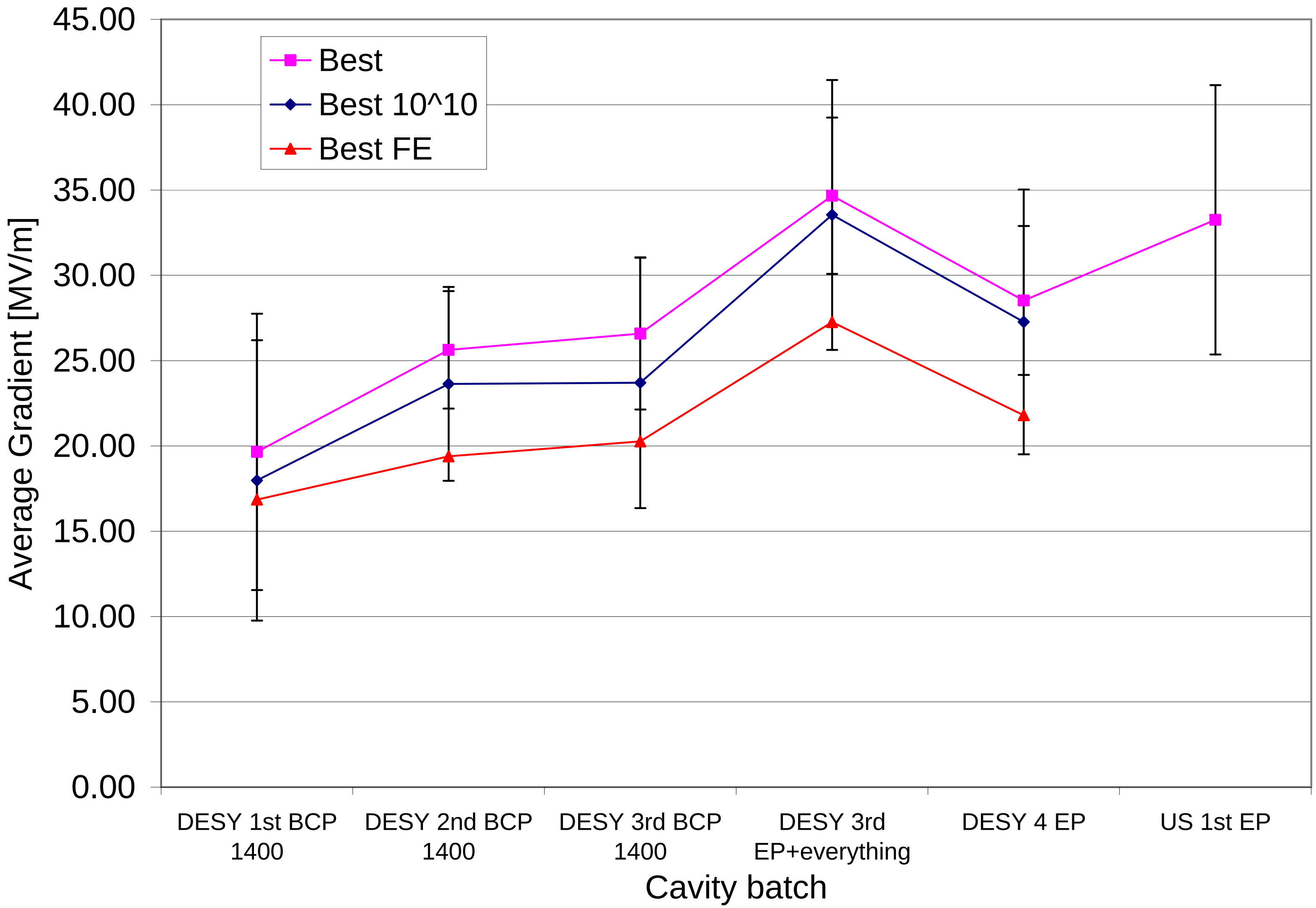
#2 Cav. 5th



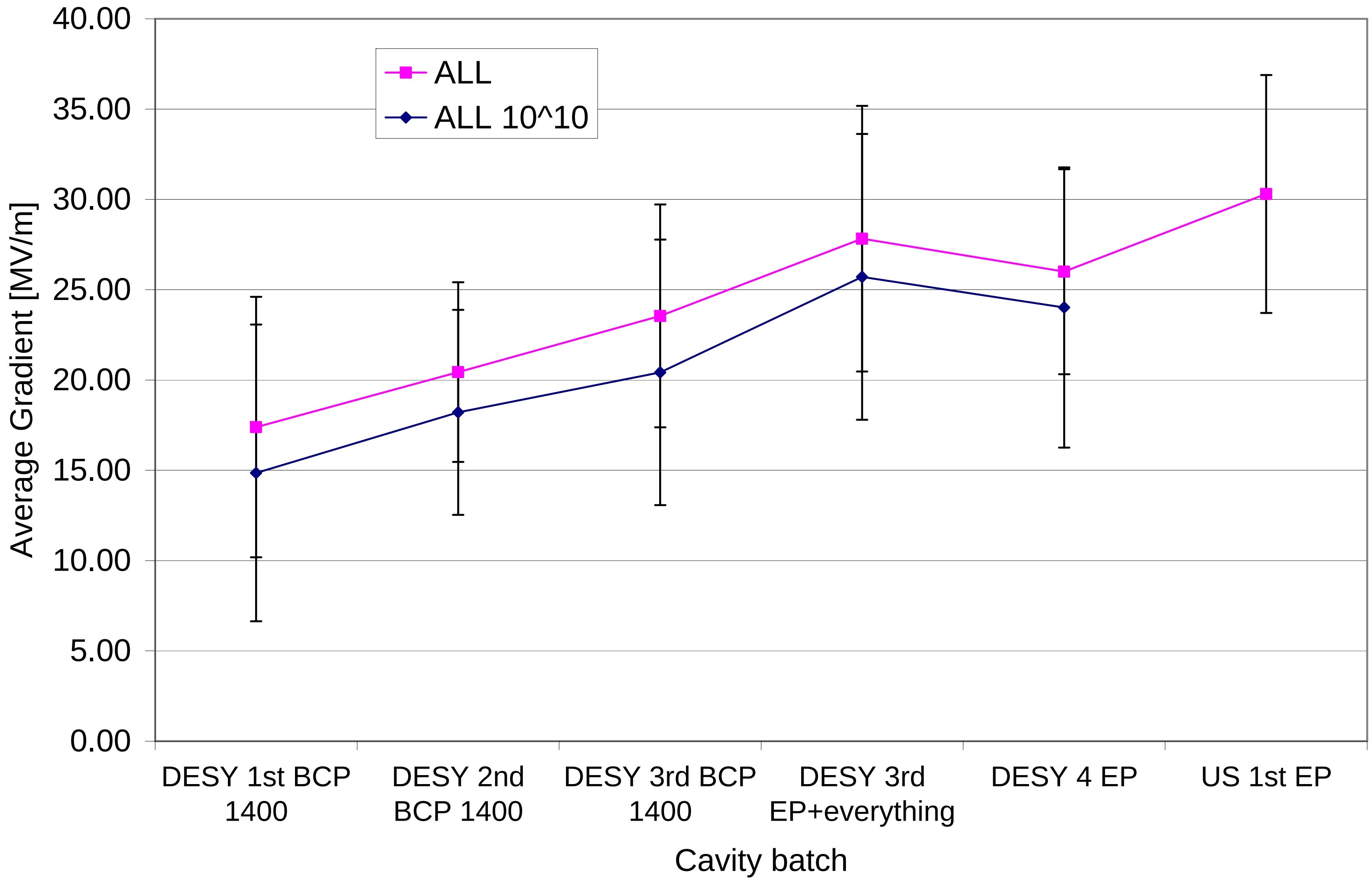
Comparison of Qualified Vendors: DESY and US Data

- DESY
  - **4 production batches**
    - 24-30 cavities each
  - **Reference:**
    - 3rd production
      - BCP batch
        - » Production-like with etching as final surface treatment
      - EP batch
        - » R&D effort to demonstrate feasibility of multi-cell EP at KEK and DESY
    - 4th production
      - First ‘production-like’ effort on EP with multi-cells
- US
  - **4 cavities total**
    - Statistics low !
    - Several tests per cavity
  - **Surface treatment**
    - Baseline: Horizontal EP at Jlab
    - Alternative: Vertical EP at Cornell
      - Data of tests with etching omitted

'Qualified' Vendor Productions: Best Test Results

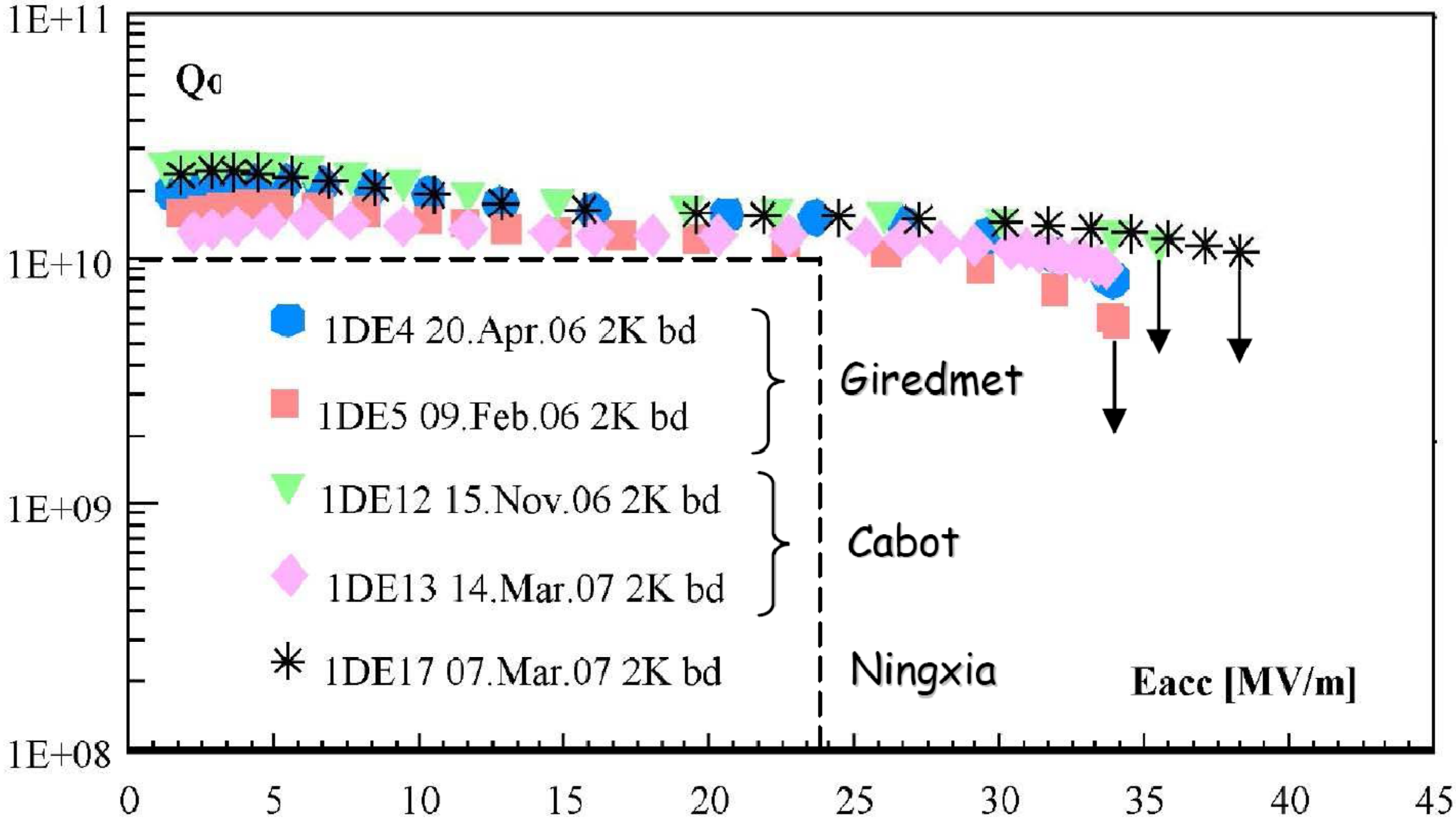


'Qualified' Vendor Productions: All Test Results



XFEL Assets: E.g. More Fine-Grain Niobium Vendors

D. Reschke et al.



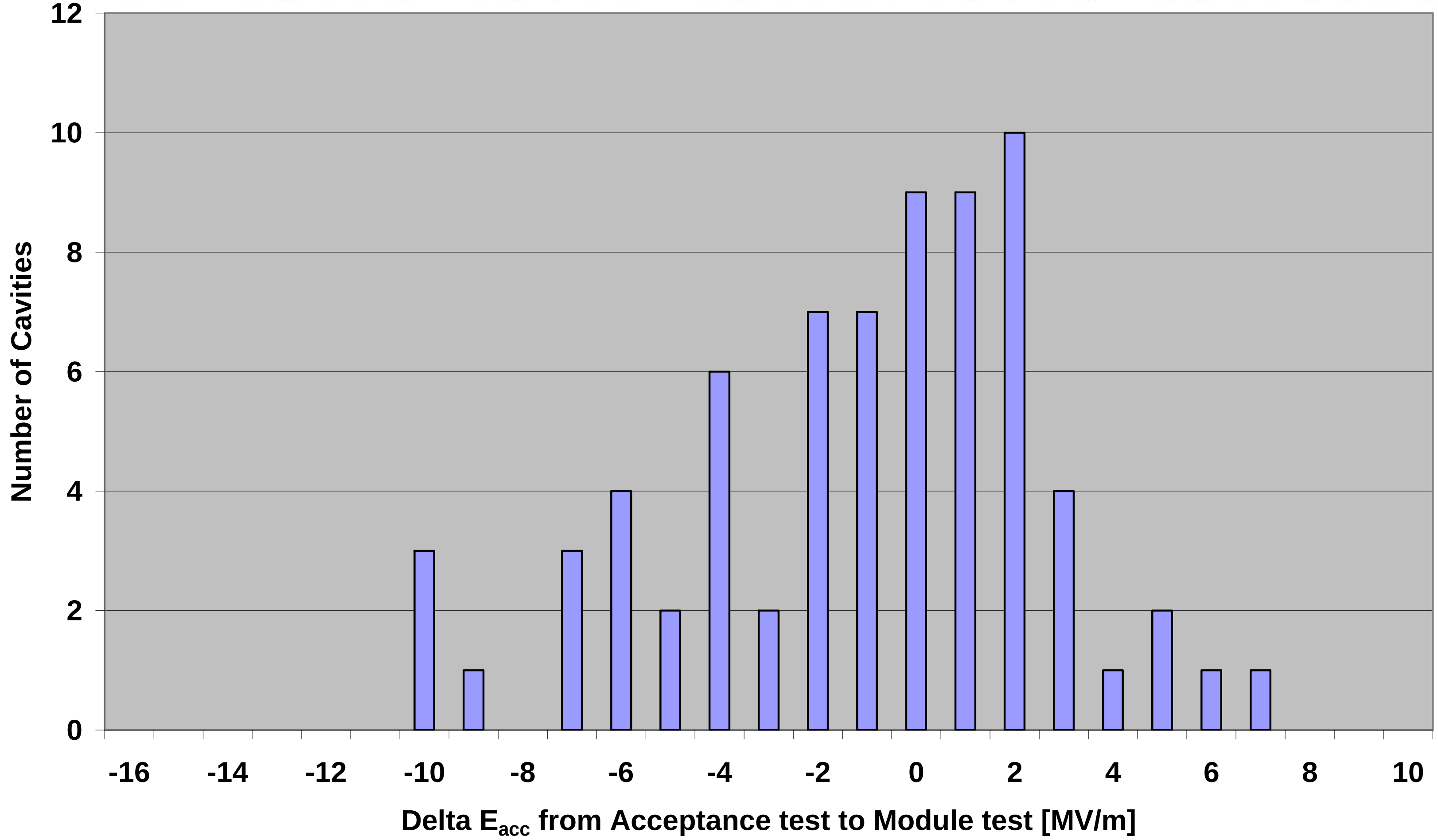
Outline

- S0S1 R&D Results
  - **S0**
    - Single-cells
    - Tight-loop
    - Production-like
  - **S1**
    - Recent tests on M6 and M7 at DESY
  - **Alternatives**
    - Material
    - Surface preparation
    - Cavity geometry

S1 R&D

- For the ILC
  - **The acceptance test gradient is specified to 35 MV/m, the operational gradient to 31.5 MV/m.**
    - Reflects experience that some performance is lost with the installation into modules e.g. M6
  - **All modules are for FLASH**
    - Schedule pressure determined final choice of cavities e.g. M6
      - Compromises made for gradient performance
- Module tests
  - **Operational gradient is steadily increasing e.g. M4, M5, M7**
    - Close agreement between VTA and module performance
  - **Systems tests for high gradient operation**
    - High power coupler performance
    - Tuners esp. fast tuners for Lorentz-force detuning compensation
    - Thermal cycling
    - Alignment and Vibration studies

S1 RF Performance: Compare Acceptance Test with Module Operational Accelerating Gradient

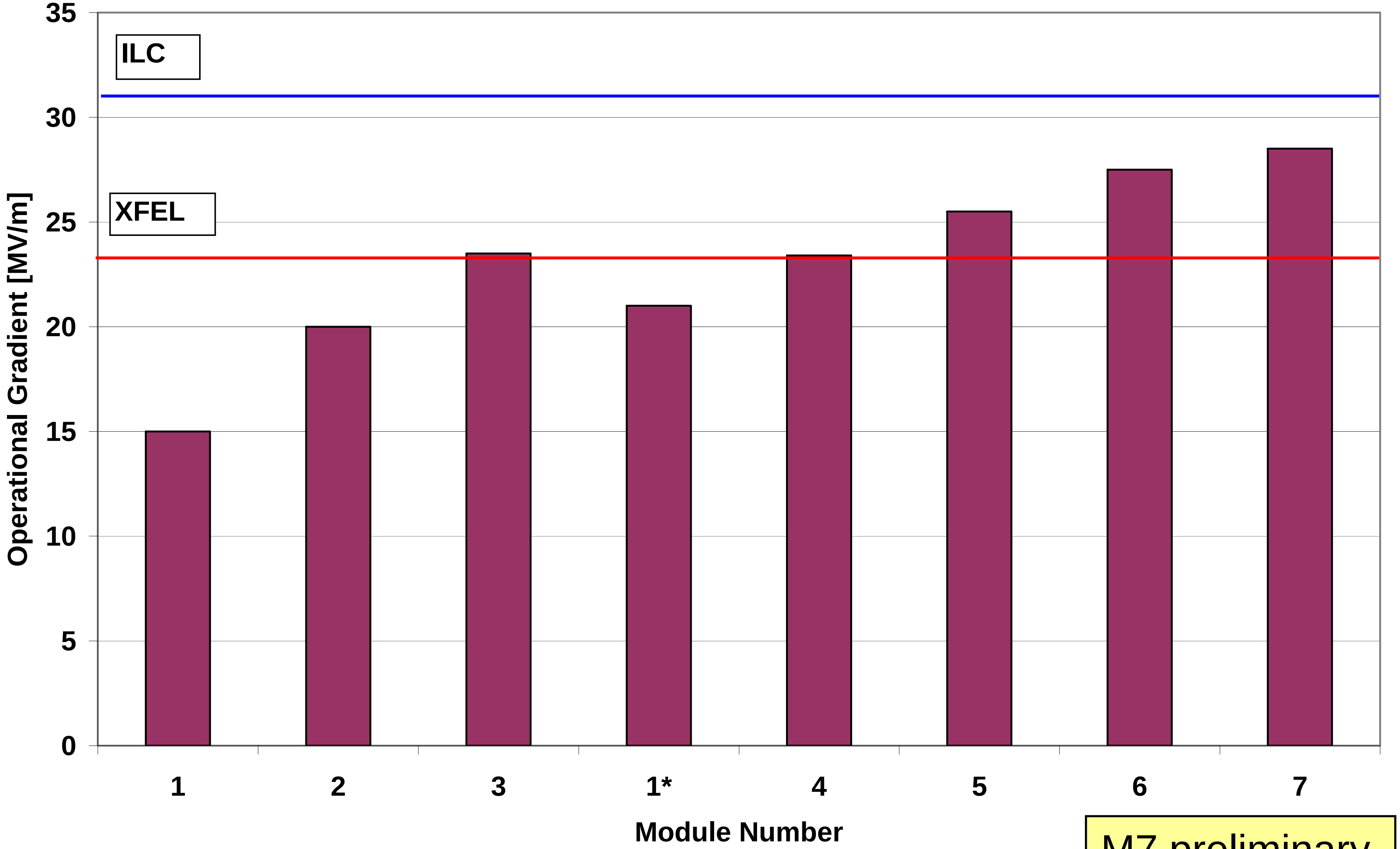


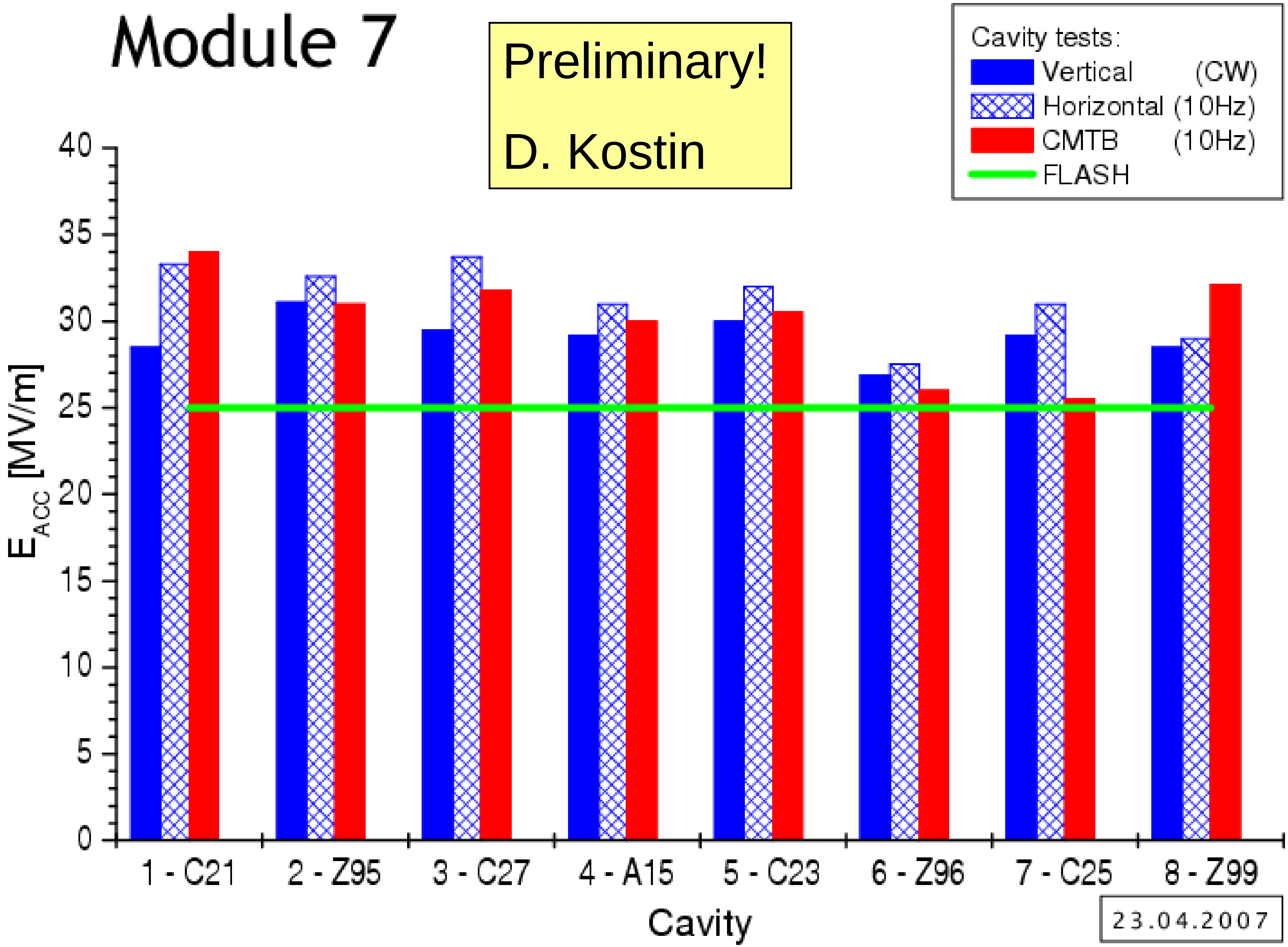
- This is the main motivation for S1
- Improvement on assembly procedures needed
  - **Addressed in studies with industry also**

XFEL assets: Module Test at DESY

- High gradient modules have been assembled
  - **For installation in FLASH**
- Test in dedicated test stand possible e.g.
  - **Cavity performance**
  - **Thermal cycles**
  - **Heat loads**
  - **Coupler conditioning**
  - **Fast tuner performance**
  - **(LLRF tests)**
- Part of the ongoing preparation work for XFEL

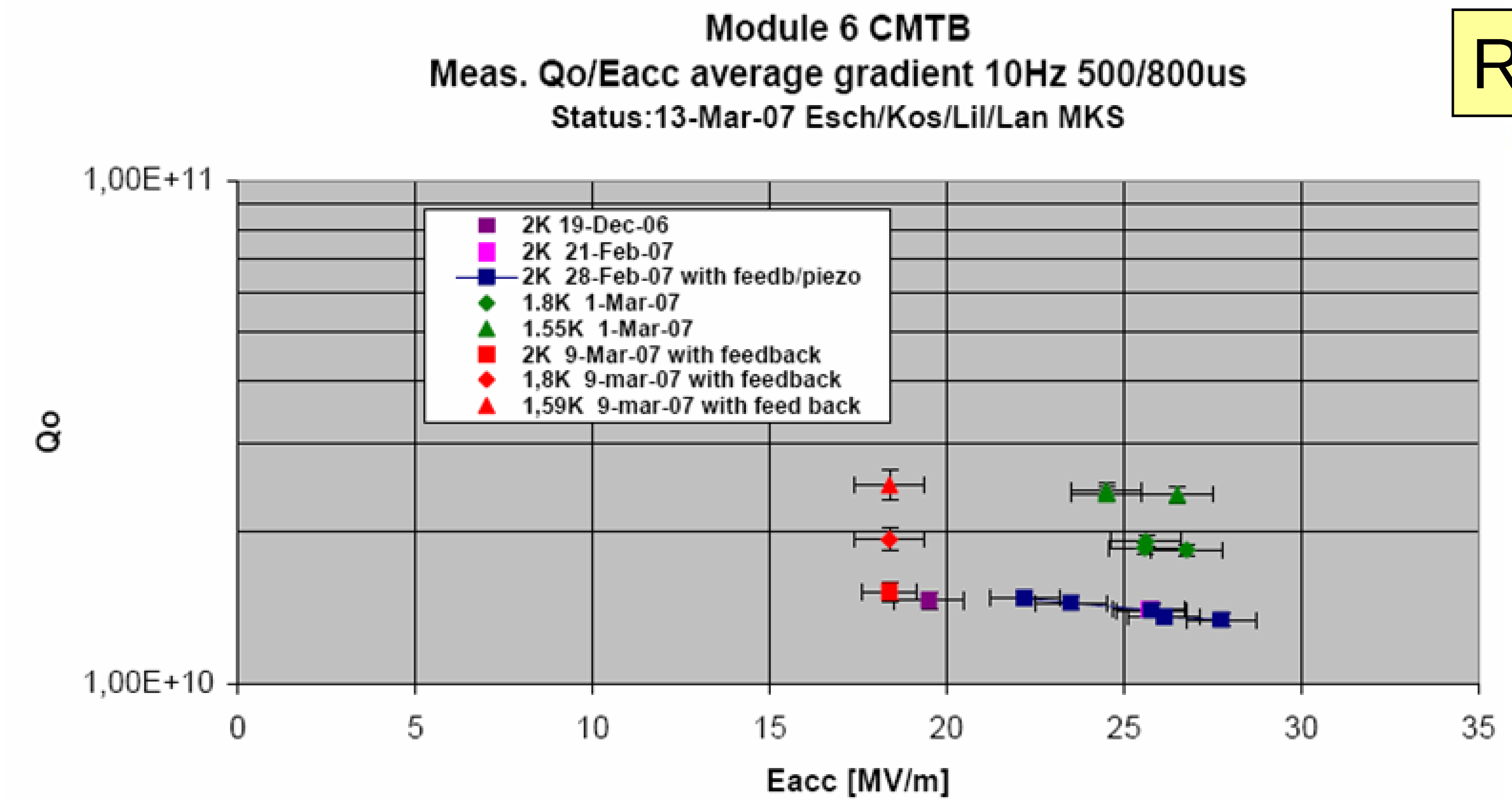
S1 RF Performance: Accelerator Module Operational Gradients

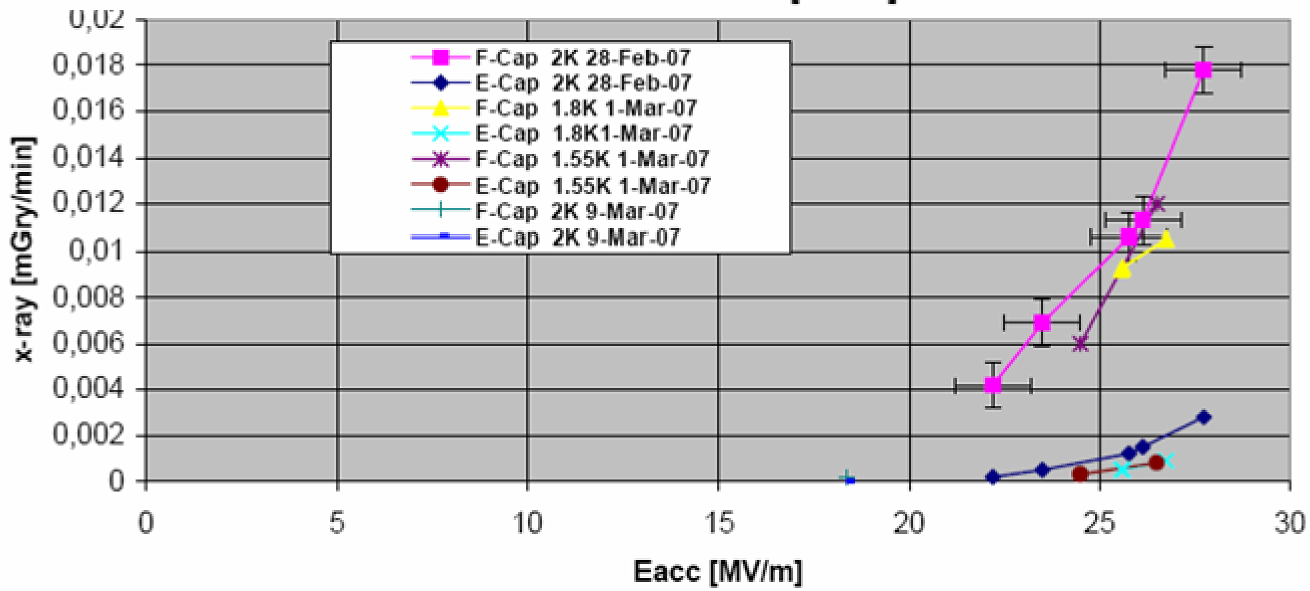




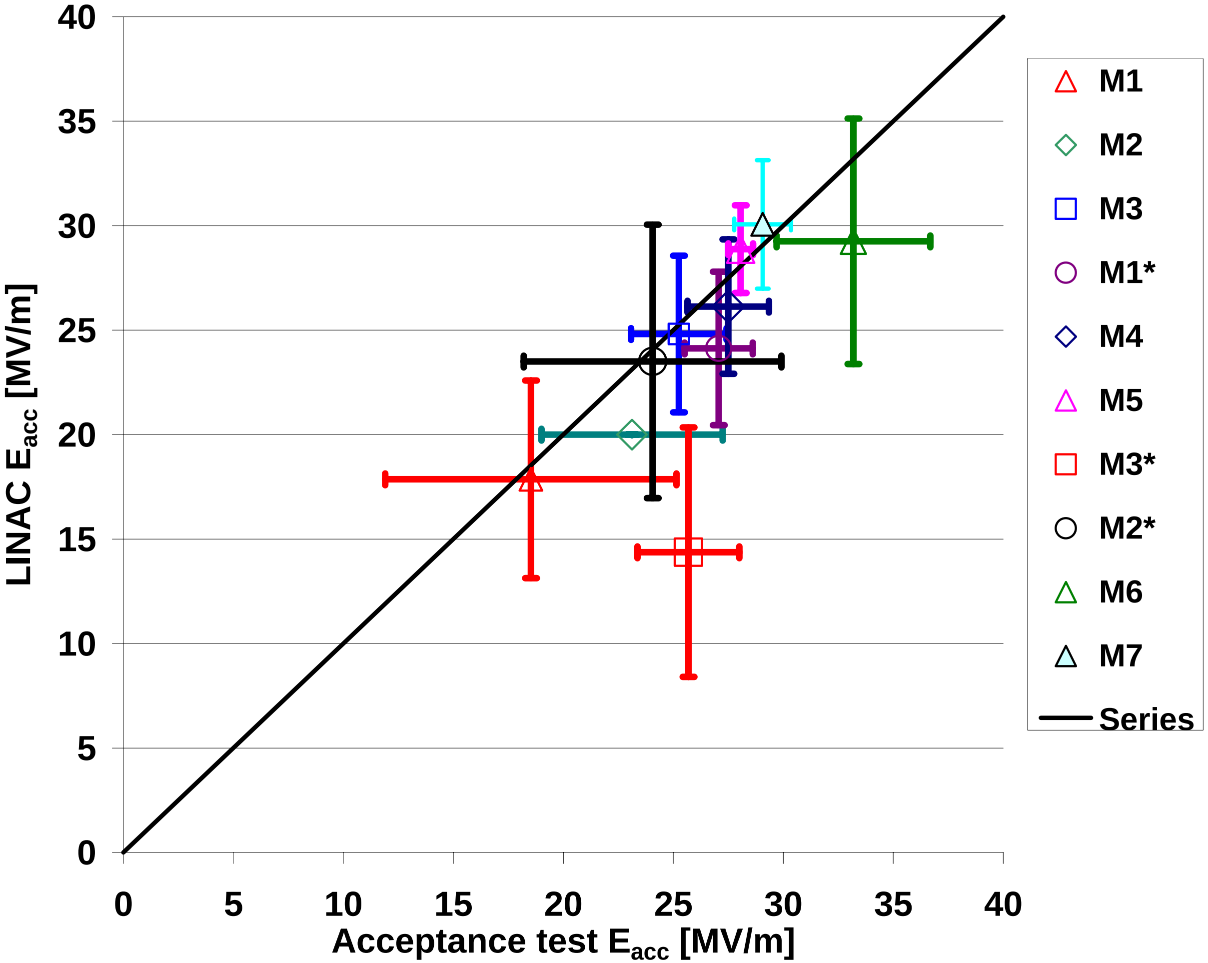
Module 7
Preliminary!
D. Kostin
Cavity tests:
Vertical (CW)
Horizontal (10Hz)
CMTB (10Hz)
FLASH
E_ACC [MV/m]
0
5
10
15
20
25
30
35
40
1 - C21
2 - Z95
3 - C27
4 - A15
5 - C23
6 - Z96
7 - C25
8 - Z99
Cavity
23.04.2007

R. Lange


Module 6 CMTB
Meas. Qo/Eacc average gradient 10Hz 500/800us
Status:13-Mar-07 Esch/Kos/Lil/Lan MKS
Qo
Eacc [MV/m]
2K 19-Dec-06
2K 21-Feb-07
2K 28-Feb-07 with feedb/piezo
1.8K 1-Mar-07
1.55K 1-Mar-07
2K 9-Mar-07 with feedback
1,8K 9-mar-07 with feedback
1,59K 9-mar-07 with feed back


x-ray [mGry/min]
Eacc [MV/m]
F-Cap 2K 28-Feb-07
E-Cap 2K 28-Feb-07
F-Cap 1.8K 1-Mar-07
E-Cap 1.8K1-Mar-07
F-Cap 1.55K 1-Mar-07
E-Cap 1.55K 1-Mar-07
F-Cap 2K 9-Mar-07
E-Cap 2K 9-Mar-07

S1 RF Performance: LINAC vs. Vertical (Cavity Average Gradients)



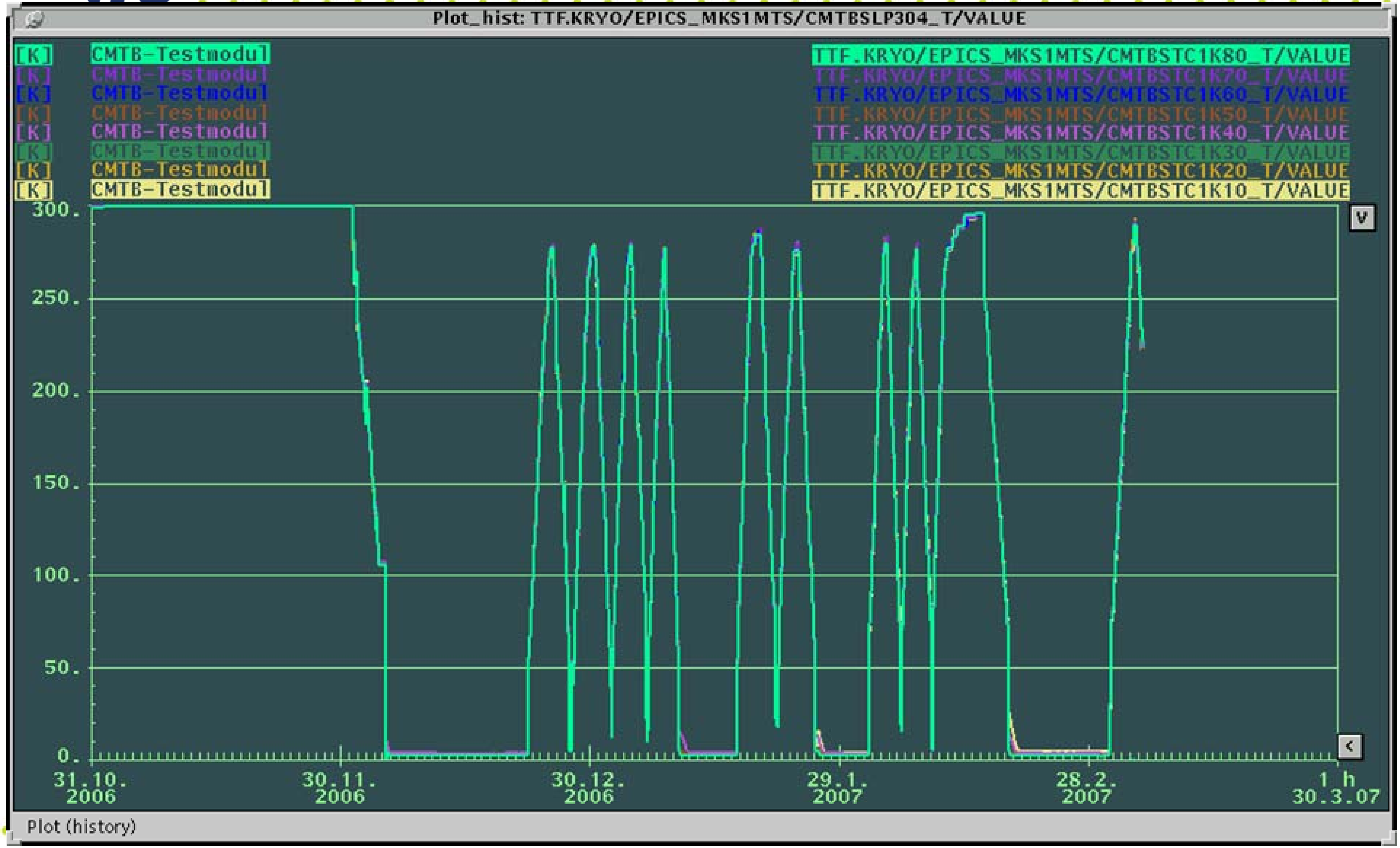
- Several Modules met expectations
  - **E.g. M4, M5, M7**
- M6 did not
  - **2 cavities degraded**
  - **Large spread in gradients in acceptance test due to time pressure for installation into FLASH**
- M3* is a very special case
  - **Coupler disassembly wrong**
  - **Repair with non-standard treatment and no acceptance test on 4 out of 5 'repaired' cavities**
  - **Time Pressure: Module needed for installation**

- TTF type 3 module
  - **Heat load static (expected value)**
    - 40 /80 K: 80 Watt +/- 5 (75 Watt)
    - 4 K: 13 Watt +/- 2 (13 Watt)
    - 2 K: 3.5 Watt +/-1.5 (2.8 Watt)
    - Note: 2 Endcaps lead to higher loss!
  - **Module dynamic losses 20 / 22 / 25 MV/m**
    - 40 /80 K:20.9 / 22.5 / 24.3 Watt (~3.5 Watt /coupler@25 MV/m)
    - 4 K: <1 / <1 / 1 Watt (0.1 Watt/coupler@25)
    - 2 K: 2.81/ 3.57 / 5.13 Watt (see also Q(E) below)
  - **No leaks occurred in 11 thermal cycles**
  - **Alignment over thermal cycles**
  - **Vibration measurements**

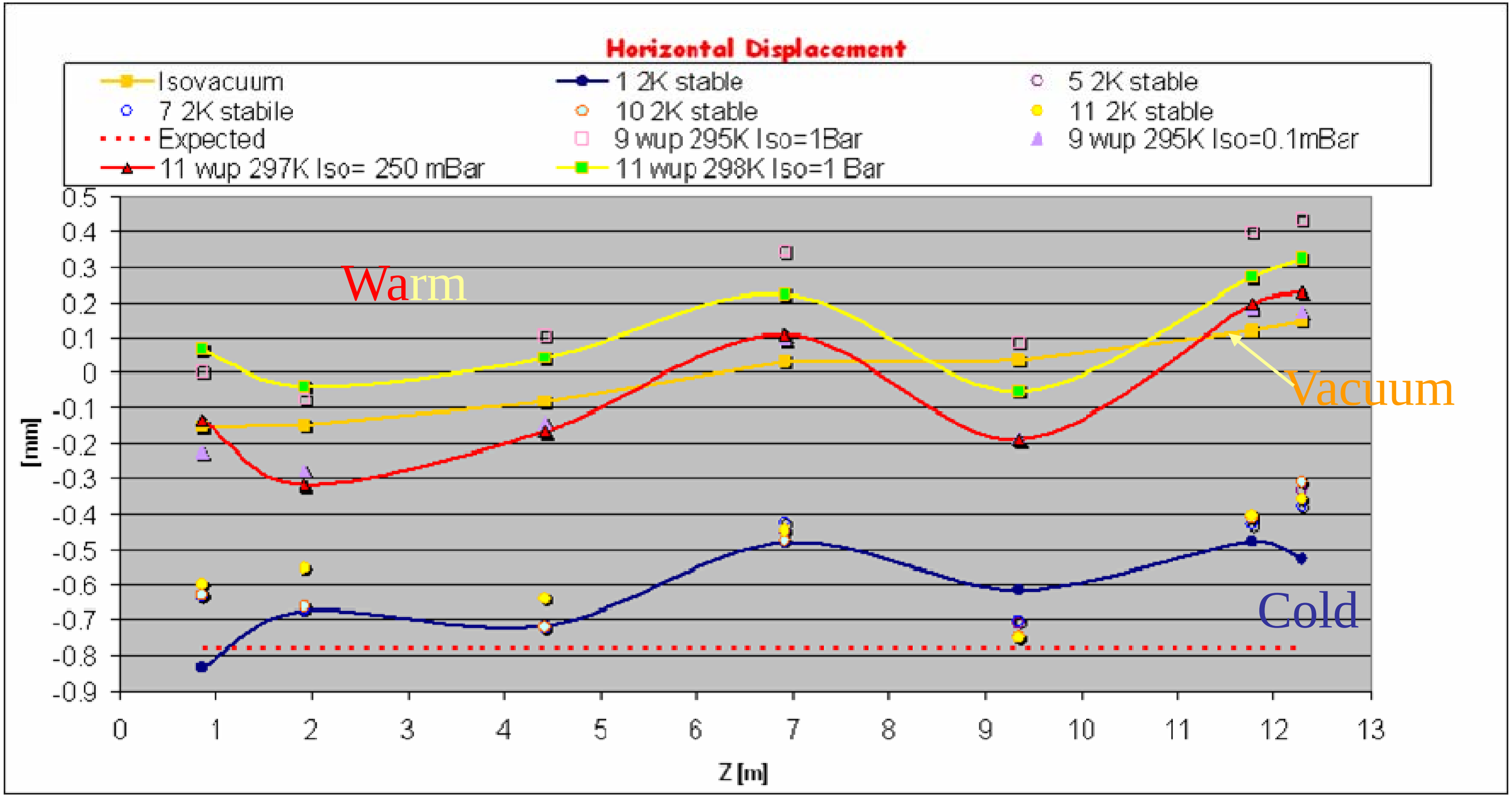
CMTB Module 6 during 11th cool down

Status:06-March-07

R. Lange



Cooldown and Warmup data for different cycles: Horizontal Displacements (only stable T points considered)

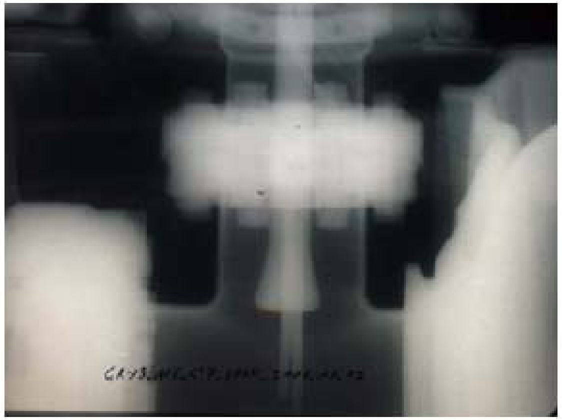


A. Bosotti

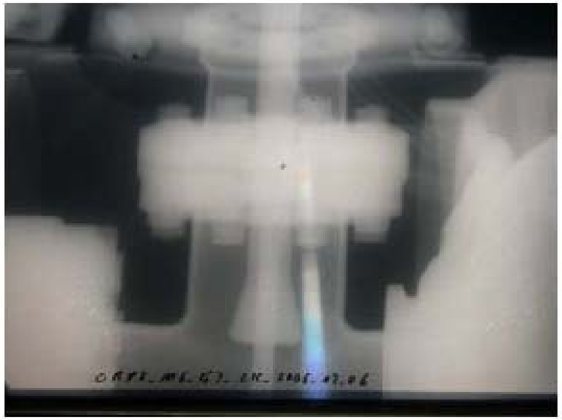
Longitudinal Position: Xray of Coupler Antenna (C7)

(Ansicht Y-Achse)

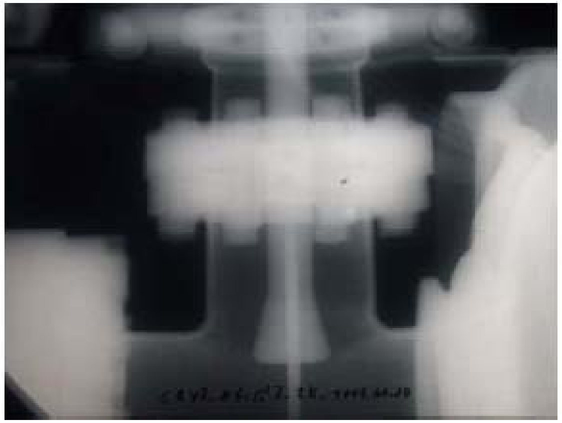
300 K vor
1 therm.
Zyklus



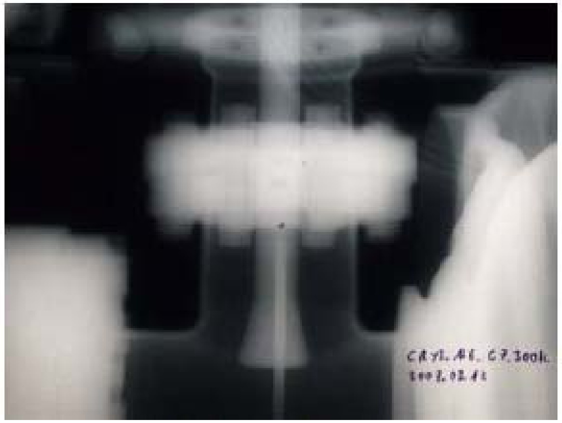
2 K nach
1 therm.
Zyklus



2 K nach
5 therm.
Zyklus



300 K nach
11 therm.
Zyklus

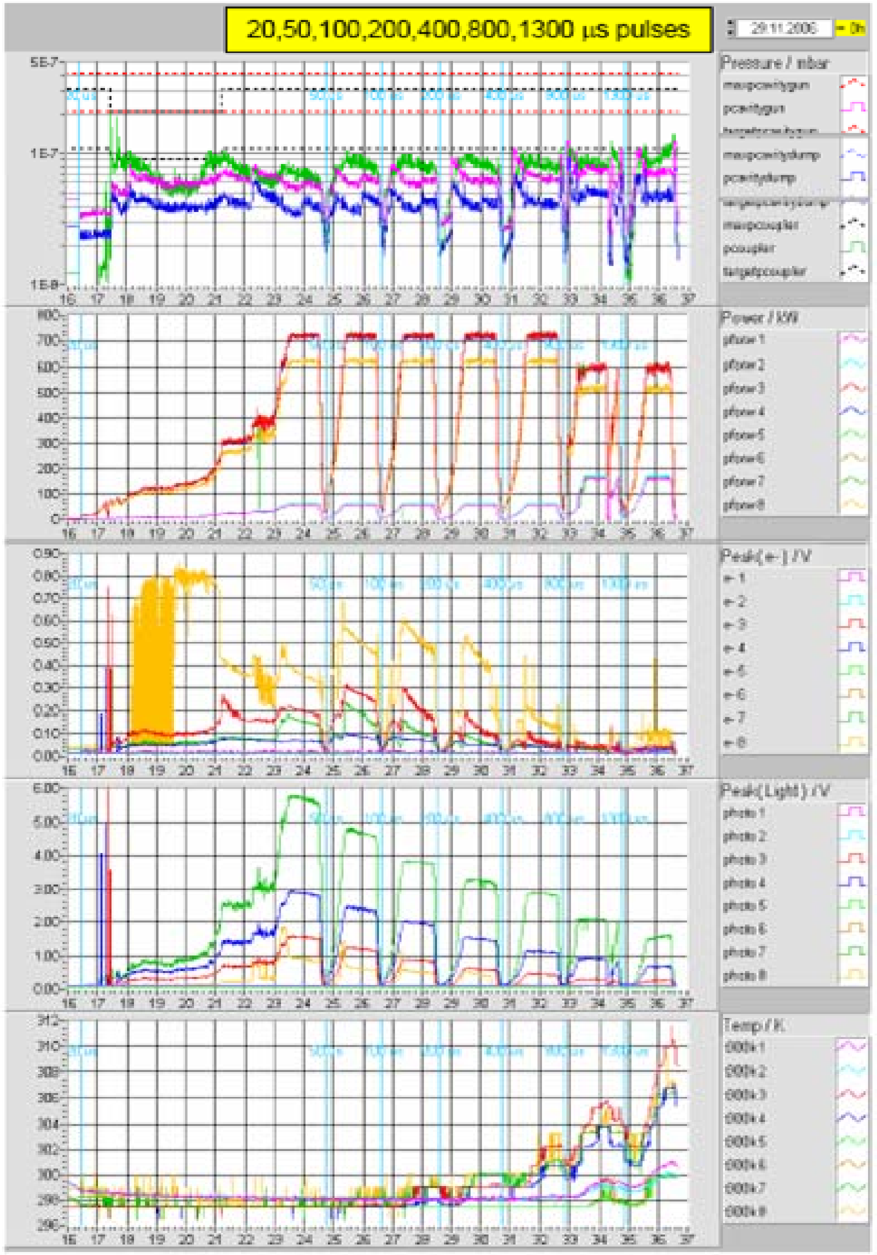


← Beam direction

K. Jensch

S1 Systems Test: Coupler Processing

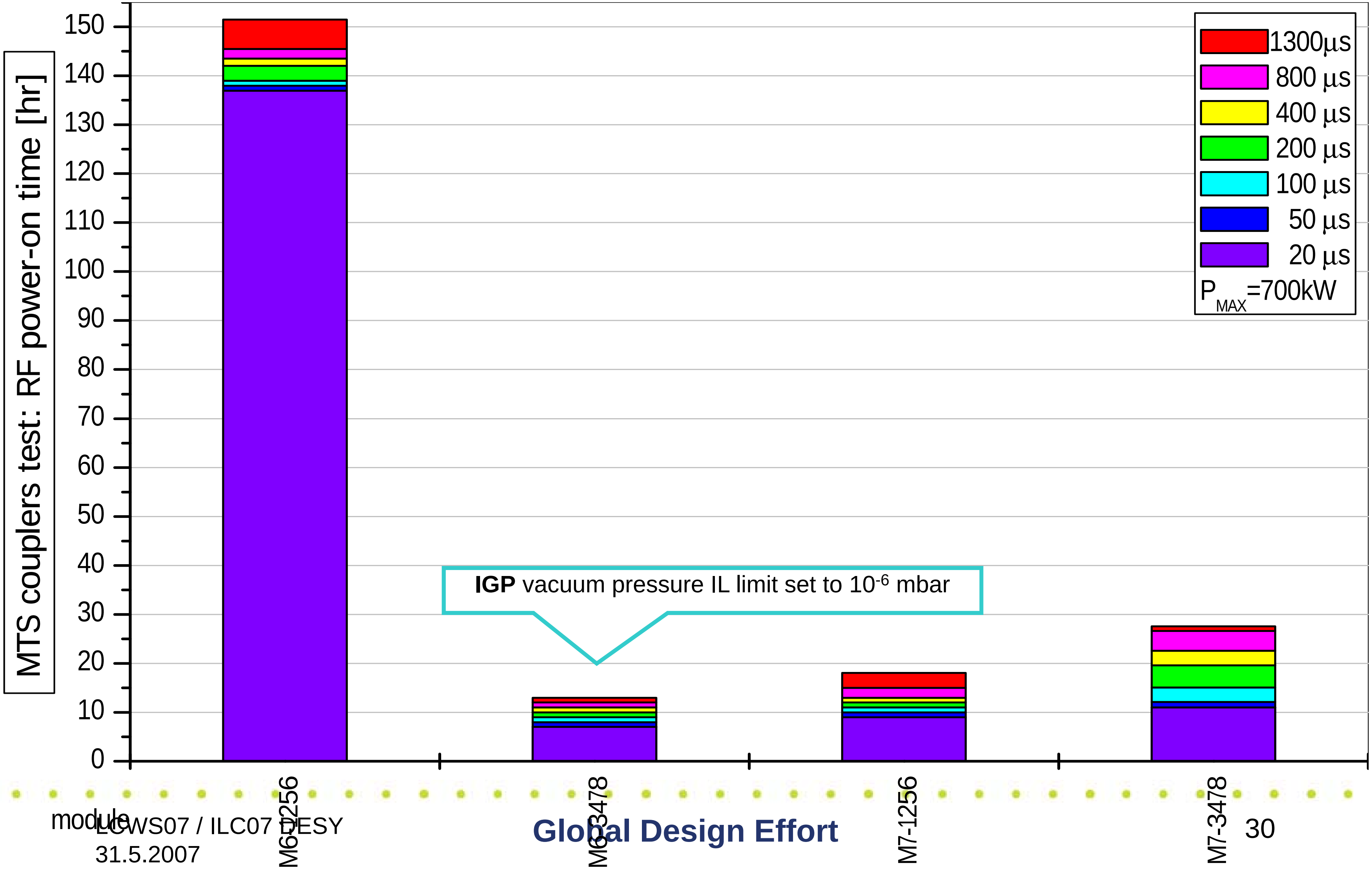
- Done in to steps
  - **1st set of 4 couplers**
    - Very tight vacuum interlock thresholts
  - **2nd set of 4 couplers**
    - Used 'relaxed' vacuum interlock thresholts
- Very fast processing
  - **Due to improved handling after pre-processing at LAL Orsay**
  - **Comparable to individual cavity high power test results**
  - **M7 preliminary!**



D. Kostin

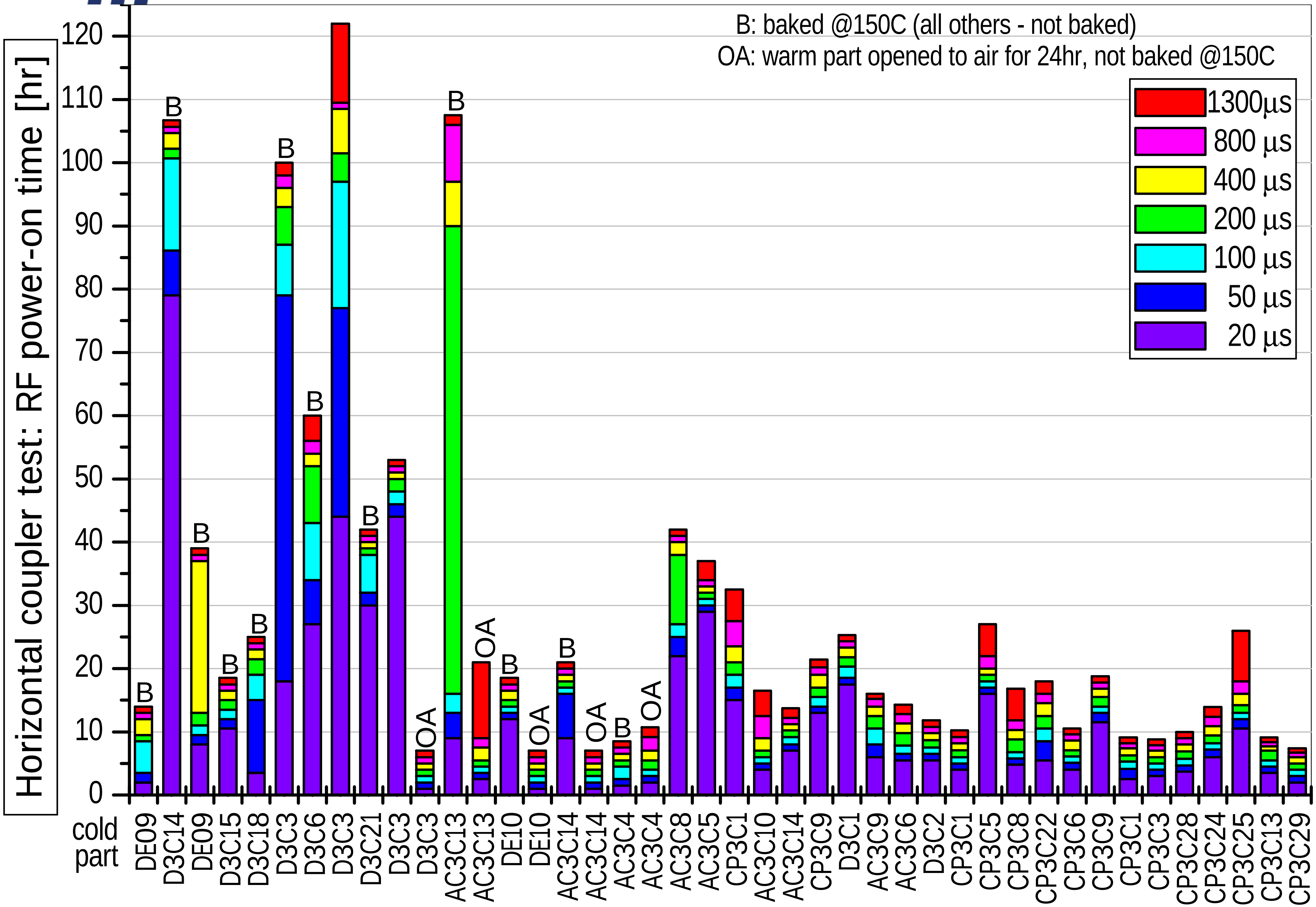
M6 and M7 RF conditioning

D. Kostin



Comparison with Horizontal Test Coupler Processing

D. Kostin



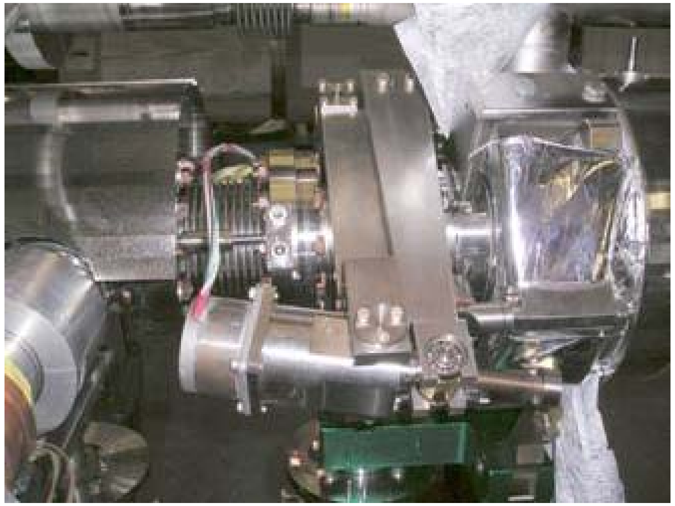
S1 Systems Tests: Fast Tuner

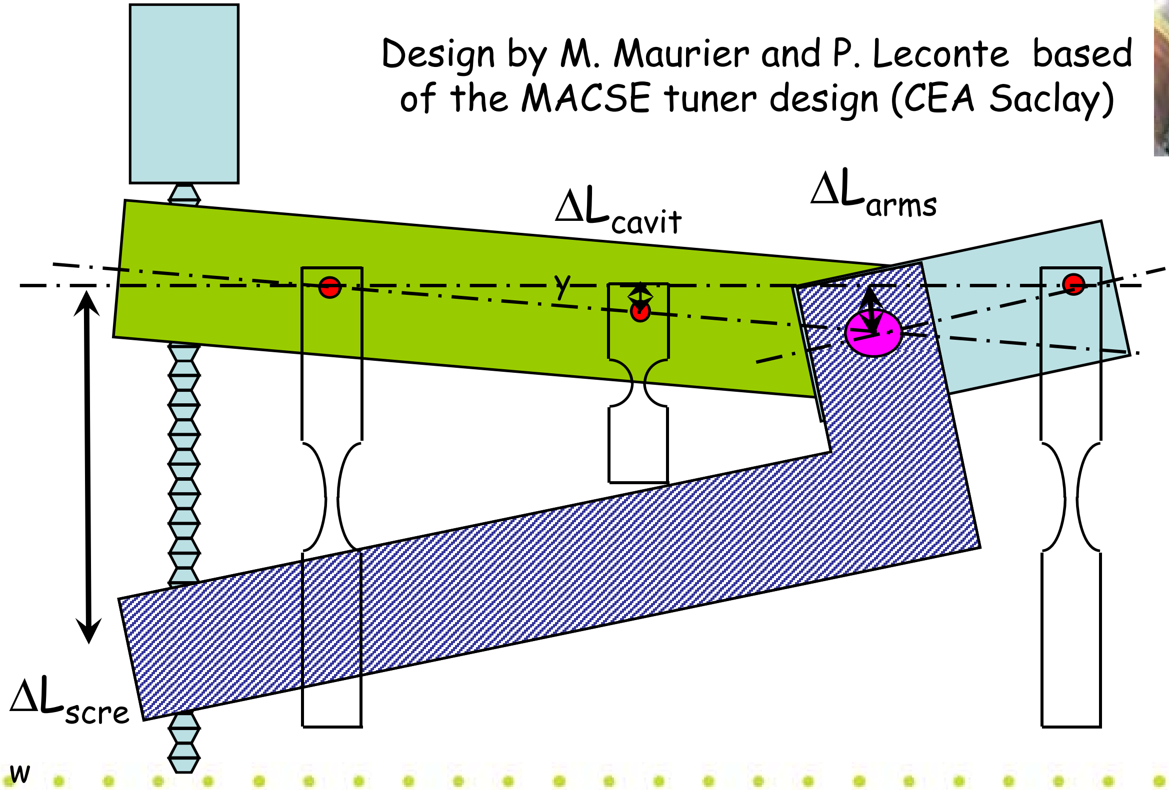
(R.Paparella –INFN, K. Przygoda – Uni. Lodz, L. Lilje DESY)

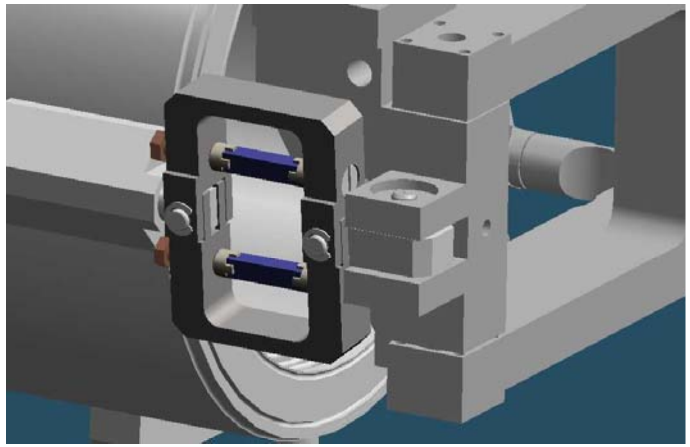
- Initial demonstration for each cavity
  - **Measure detuning**
  - **Compensate detuning individually, one after the other**
    - Classical compensation
    - ´Second oscillation´ compensation
    - No RF feedback
  - **In addition**
    - Work on piezo diagnostics: Impedance measurement
    - Measure transfer functions from one piezo to another
      - Is there any crosstalk between the cavities?
- Demonstrate compensation on full module for all cavities simultaneously
  - **With RF feedback**

Tuner Setup

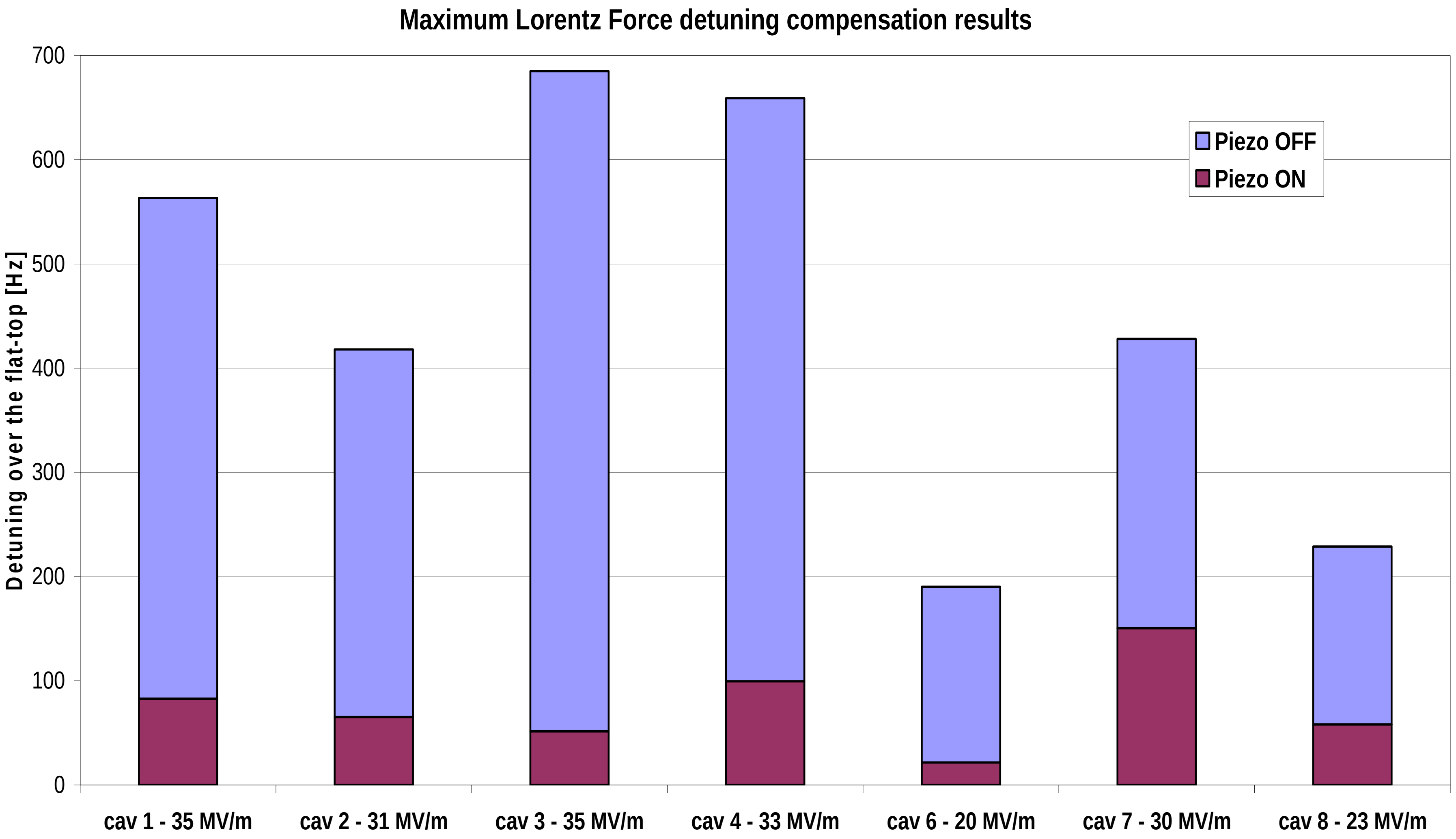
- Current design in use at FLASH
  - **Design by CEA**
  - **Fast piezo detuning introduce not from beginning**
  - **Is the backup solution for XFEL**



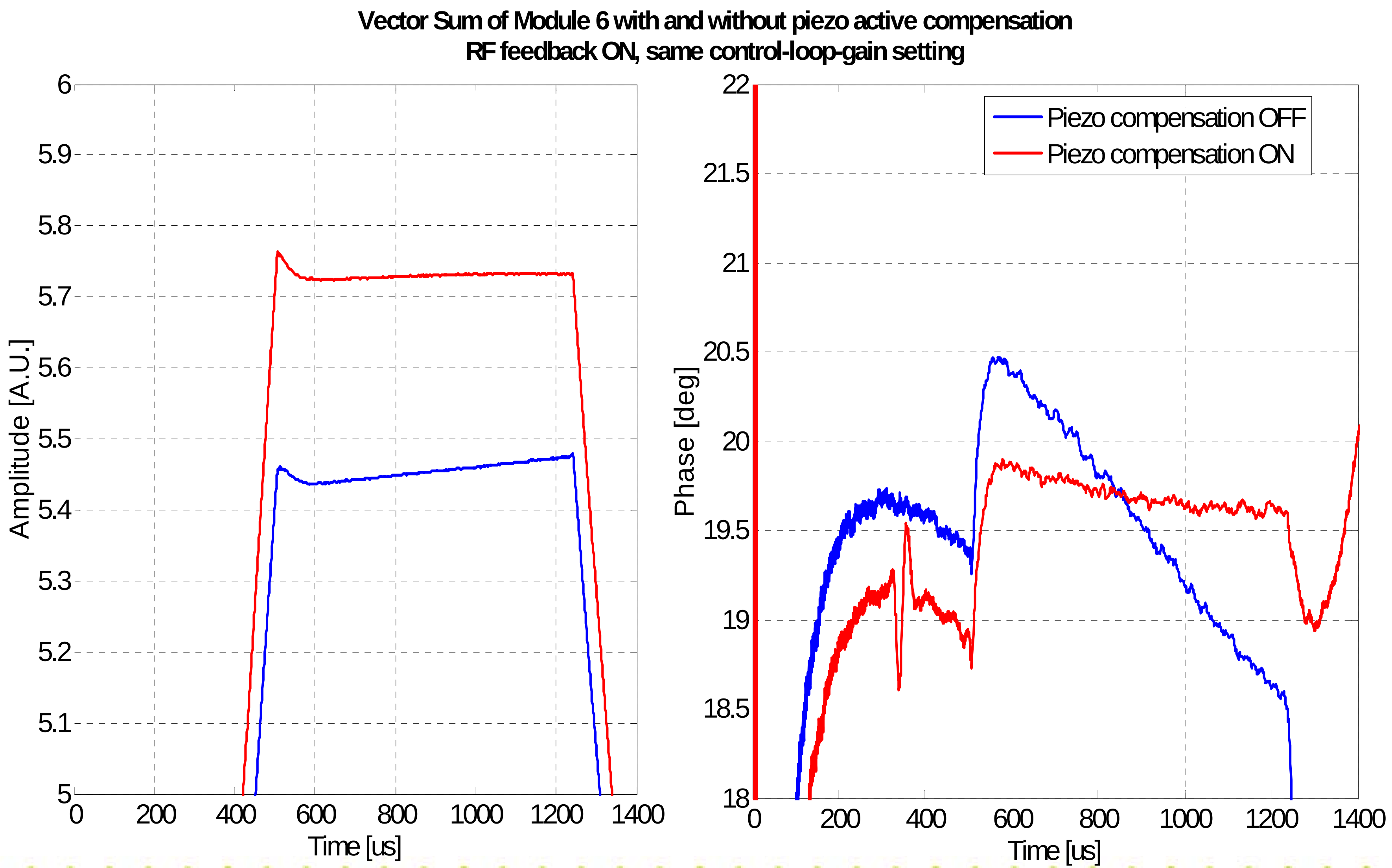




Compensated Detuning per Cavity



Operation of Full module – Vector-Sum



Conclusion on M6/M7 Tests

- CMTB has proven to be essential tool for thorough linac-independent tests of modules
- M6 and M7 have passed several important tests
  - Coupler processing smooth and short
  - Alignment over several thermal cycles was repeatable (M6)
  - No leaks occurred during cycling
  - Piezo compensation
  - Vibration in warm o.k. (M6 done, M7 underway)
- Nonetheless some issues remain
  - Cavity performance degradation
  - Vibration in cold state need more still more understanding
    - Nonetheless a clear suspect for the ~30 Hz peak has been found
    - M7 results not yet available
- Minor evolutions in design will be tested on M8
  - Important step toward a XFEL prototype test

Outline

- S0S1 R&D Results
  - **S0**
    - Single-cells
    - Tight-loop
    - Production-like
  - **S1**
    - Recent tests on M6 and M7 at DESY
  - **Alternatives**
    - Material
    - Surface preparation
    - Cavity geometry

XFEL is an Important Asset

- Continuous production of cavities in line of preparation improvements
  - **Is a significant part of the cavity data set, as you have seen**
- Material issues
  - **Scanning for a large batch of material**
  - **Qualifying more niobium vendors**
  - **Alternatives: Large-grain material is still an option for the XFEL**
- Pre-series will start 2008
  - **EP is becoming industry process from autumn**
- Design for manufacturing for the cavities
  - **Review types of welds and welding procedures**
- Quality assurance
  - **Defining a reasonable and affordable QC procedure**
- Module design and assembly has been reviewed by industry
  - **Report is due soon**
- (Coupler industrialisation)

XFEL Assets: E.g. Module Transportation

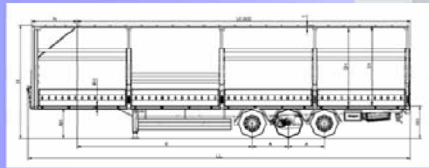
ACCEL Cryomodule Assembly Study I

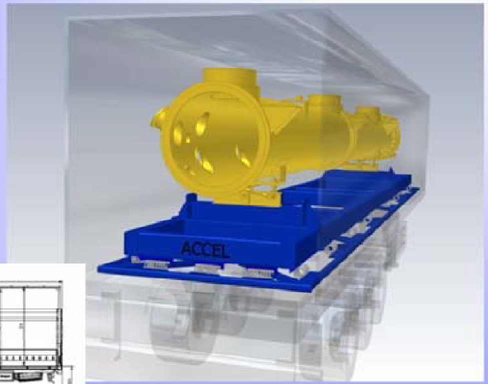
S. Bauer, B. Griep, M. Pekeler, H. Vogel, J. Zeutschel
ACCEL Instruments GmbH
Friedrich-Ebert-Str. 1
51429 Bergisch Gladbach

TTC meeting at FNAL, April 23-26, 2007

possible solution for XFEL module transports

- transport frame is mounted on truck
- truck can be loaded with crane from top
- truck travels between assembly site and XFEL site
- available length: 13.6 m
- available width 2.5 m
- available height: 2.5 m
- allowable weight: 12 t



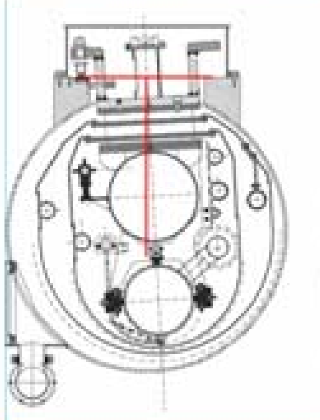


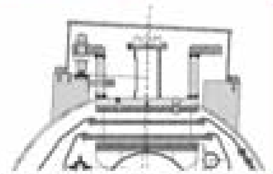
Caution: top loaded road semi trailer hard to find outside EU. In US only hard cover or flat bed

Industry Study on the Series Production of XFEL Cryomodules

C.Boffo, W. Gärtner, S. Sattler, G. Sikler, U.-M. Tai

CM Transport Critical Components II





-A lift-off case has to be avoided.

-Bending of the post is still critical, even though distributed over three posts

-A fixture of the GRT at both ends will (widely) solve both problems (-stiffness of the GRT)

Large Grain Material (JLab)

Large Grain/Single Crystal Niobium[2]

CBMM

Ingot “D”,800 ppm Ta

Ingot “A”, 800 ppm Ta

Ingot “B”, 800 ppm Ta

Ninxia

Ingot “C”, 1500 ppm Ta

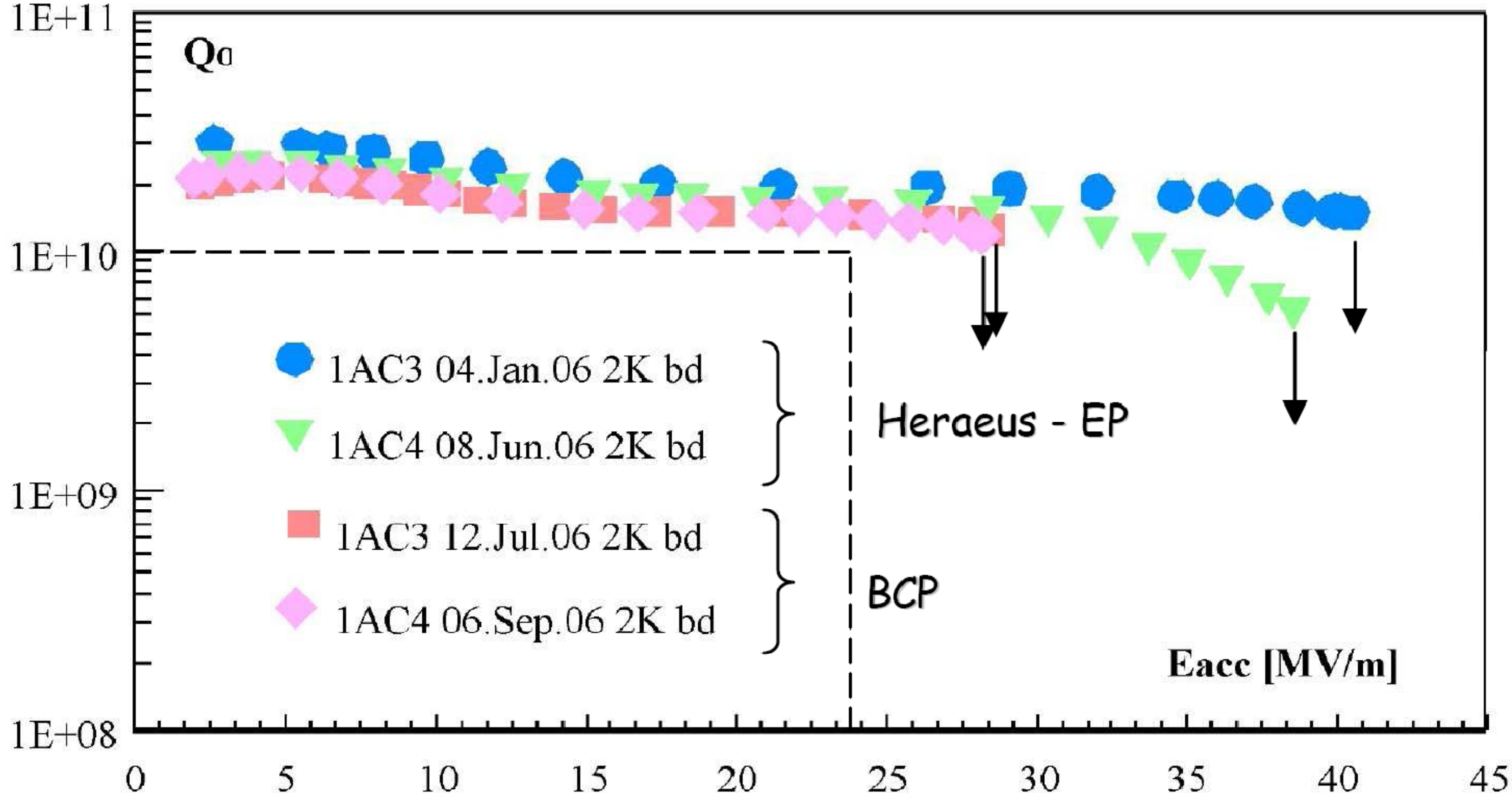
Wah Chang

Heraeus

Oct. 30 – Nov. 2, 2006

Single Crystal Workshop
Araxa, Brasil

Large Grain Material: EP and BCP

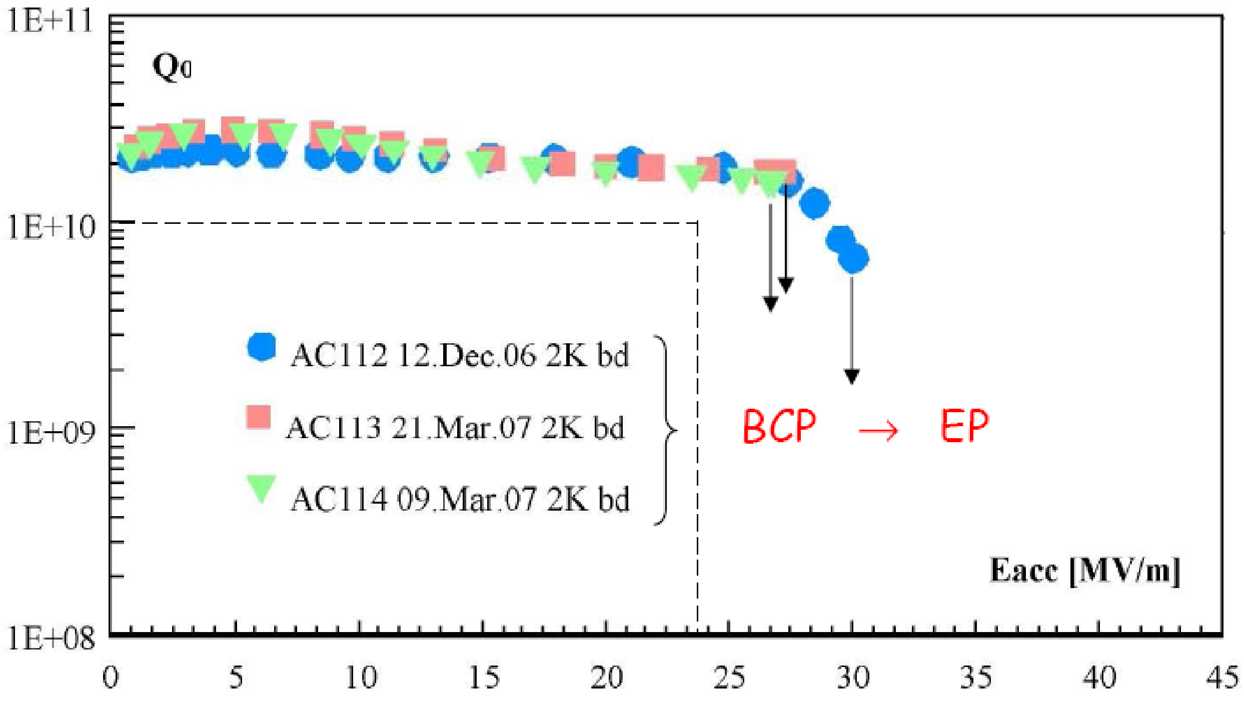


D. Reschke et al.

Large Grain Material: Multi-Cells (XFEL option)

Option : Large Grain cavities / BCP

Heraeus / Accel (three cavities)



Less fabrication steps (lower cost)

no forging-rolling

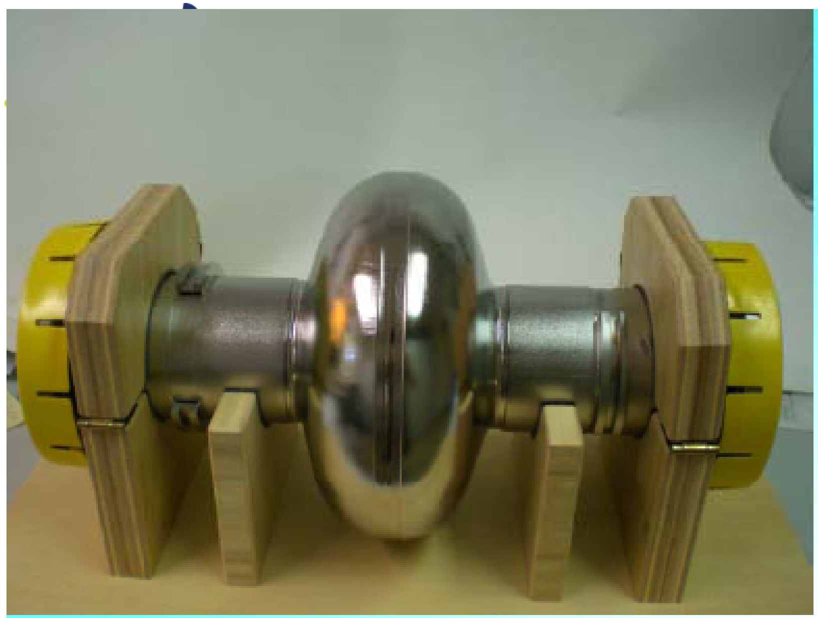
disk from ingot

(less material pollution)

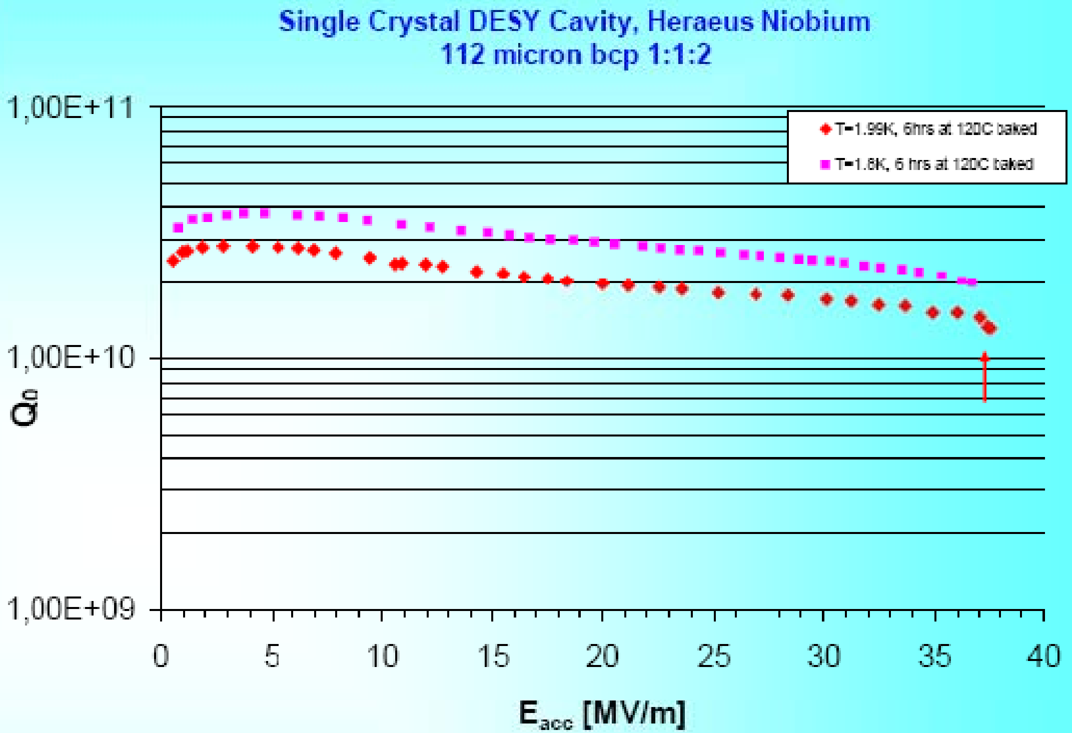
High RRR ~ 500

(avoid HT to ↗ K)

Probably higher gradients after Electropolishing (coming tests)



DESY single crystal cavity 1AC8 build from Heraeus disc by rolling at RWTH, deep drawing and EB welding at ACCEL



Q(Eacc) curve after only 112 µm BCP and in situ baking 120°C for 6 hrs.

Preparation and RF tests of P.Kneisel, JLab

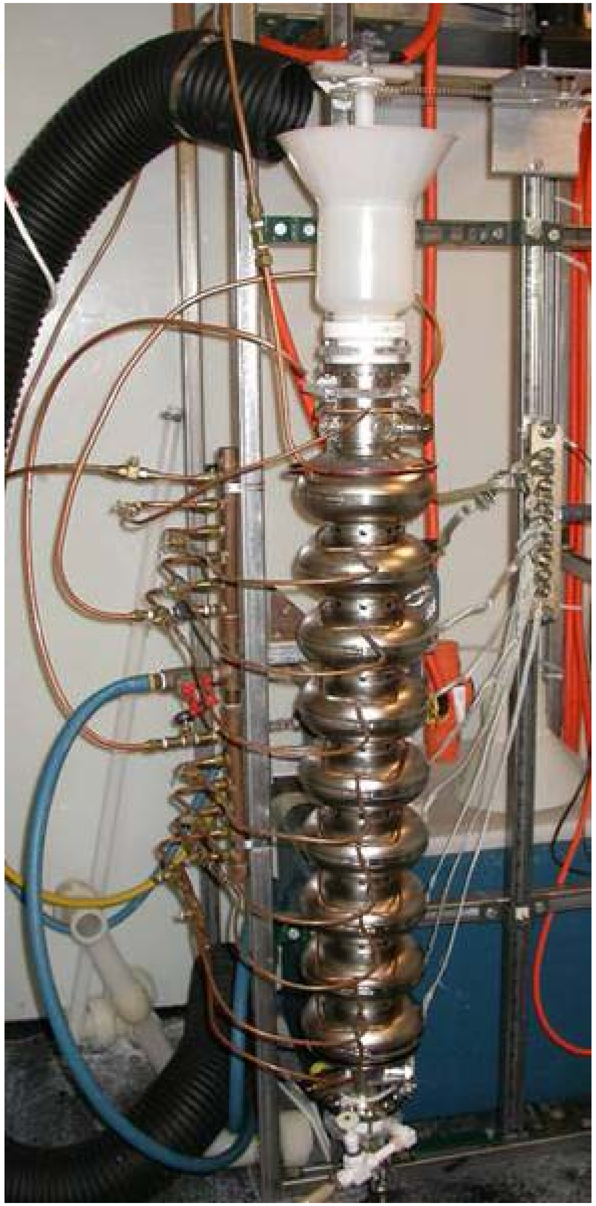
Outline

- S0S1 R&D Results
  - **S0**
    - Single-cells
    - Tight-loop
    - Production-like
  - **S1**
    - Recent tests on M6 and M7 at DESY
  - **Alternatives**
    - Material
    - Surface preparation
    - Cavity geometry

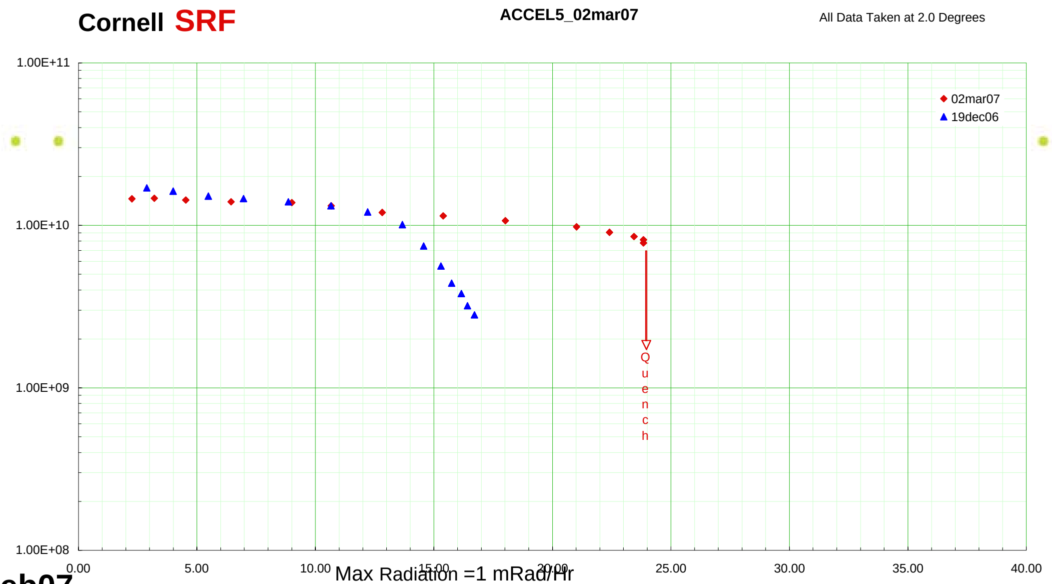
Vertical Electropolishing Set-up

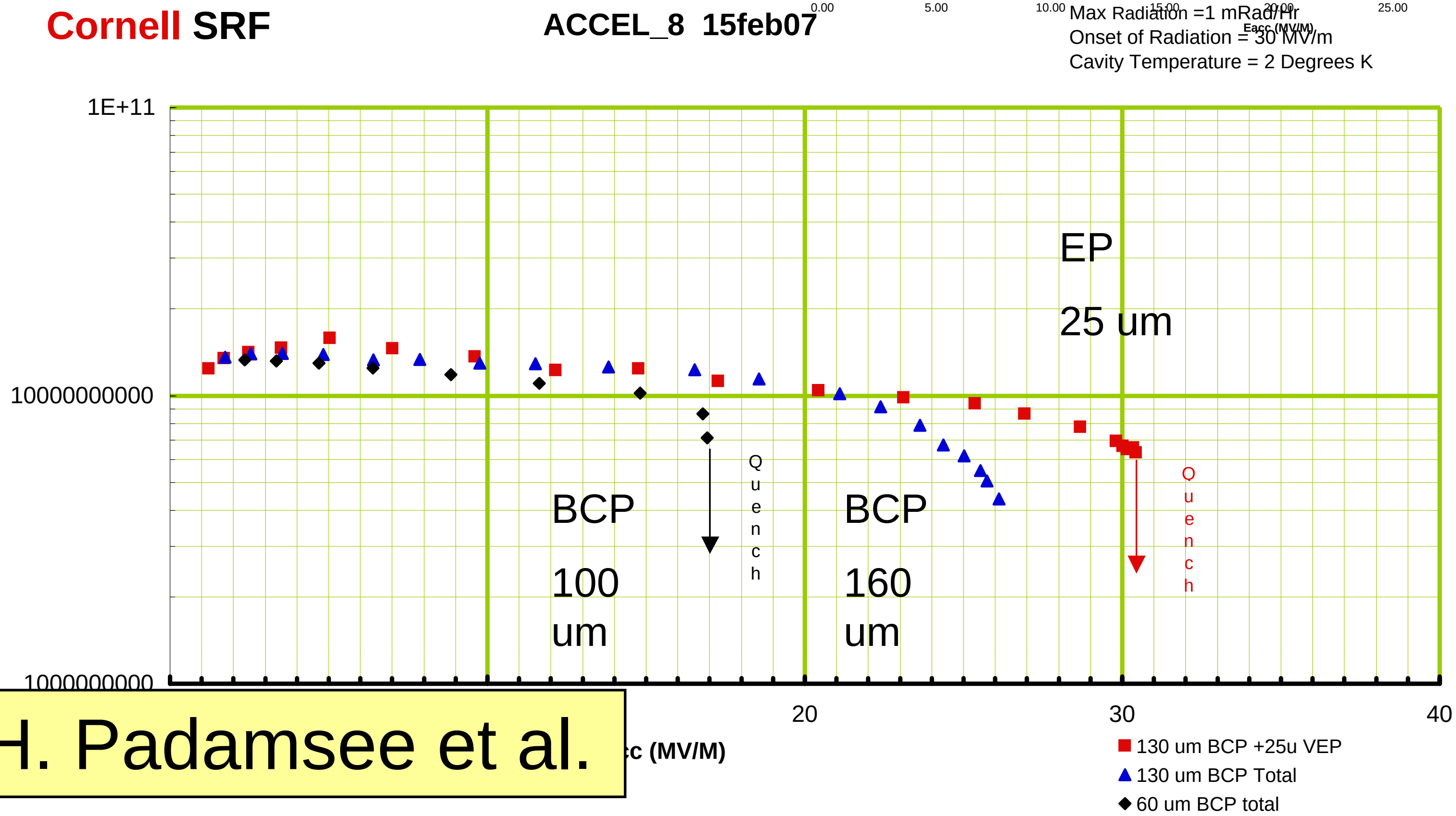
- Cornell development
- Possible benefits
- Simpler
  - **No large acid barrel, no plumbing, valves, no acid heat exchanger…**
- Less expensive to reproduce many systems
- Possible disadvantage
  - **more exposure to H**
  - **600 - 800 C, H degassing required**

H. Padamsee et al.



Vertical EP Moves Forward: ACCEL- 8 and 5 Test Results





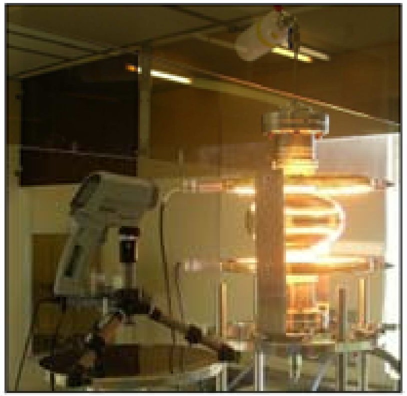
H. Padamsee et al.

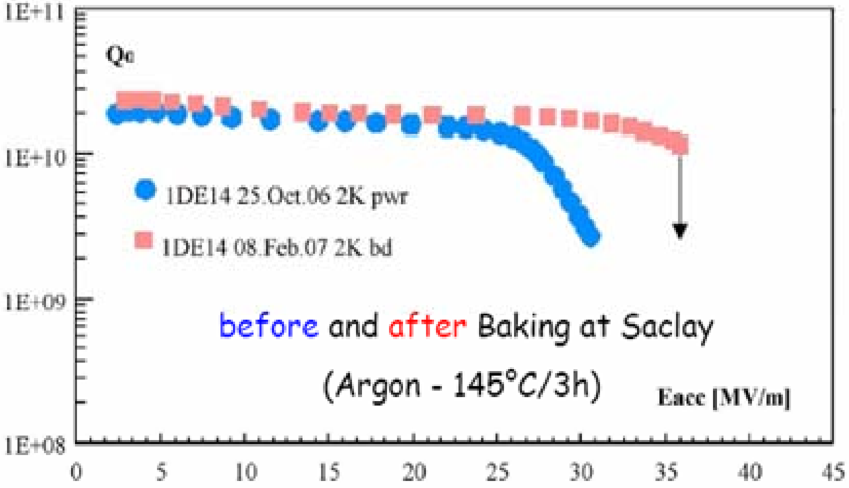
Baking

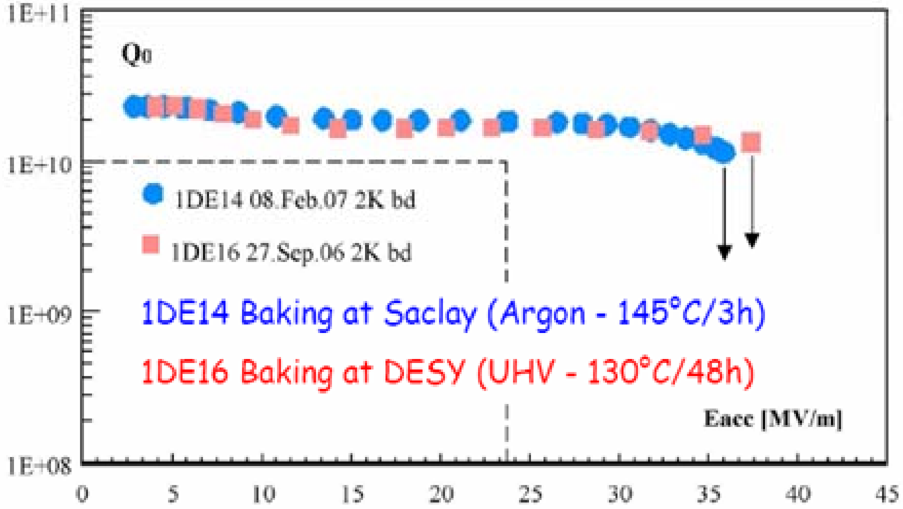
Best parameters for Baking XFEL

- Standard process : Ultra High Vacuum
  110°C/60h - 120°C/48h - 139°C/12h

- Fast Argon baking : Argon - 145°C / 3 h
  successfully tested on EP cavity







Equivalent Results
Q-drop removal
gradients performances

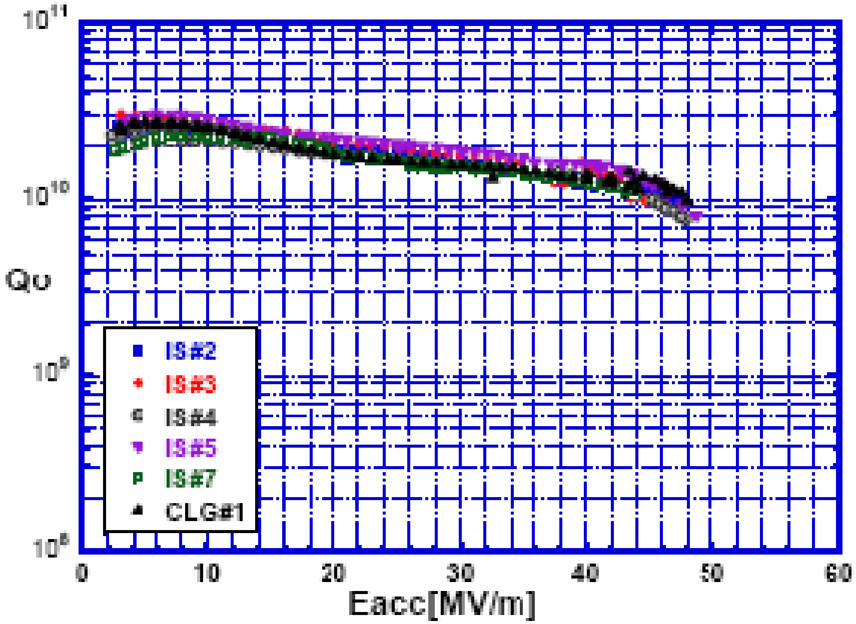
1DE14 / 1DE16 are in-house DESY twin Cavities
Plansee (Fine Grain Nb) : qualified

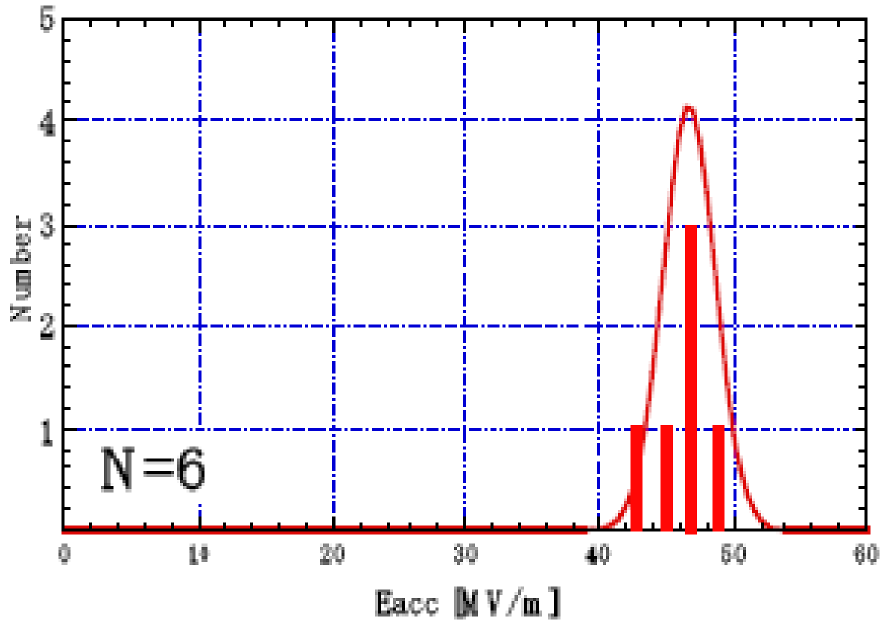
Outline

- S0S1 R&D Results
  - **S0**
    - Single-cells
    - Tight-loop
    - Production-like
  - **S1**
    - Recent tests on M6 and M7 at DESY
  - **Alternatives**
    - Material
    - Surface preparation
    - Cavity geometry

K. Saito et al.

(D) +EP(20μm)+EP(3μm, fresh, closed) +HF* +HPR+Baking (120C*48hrs)





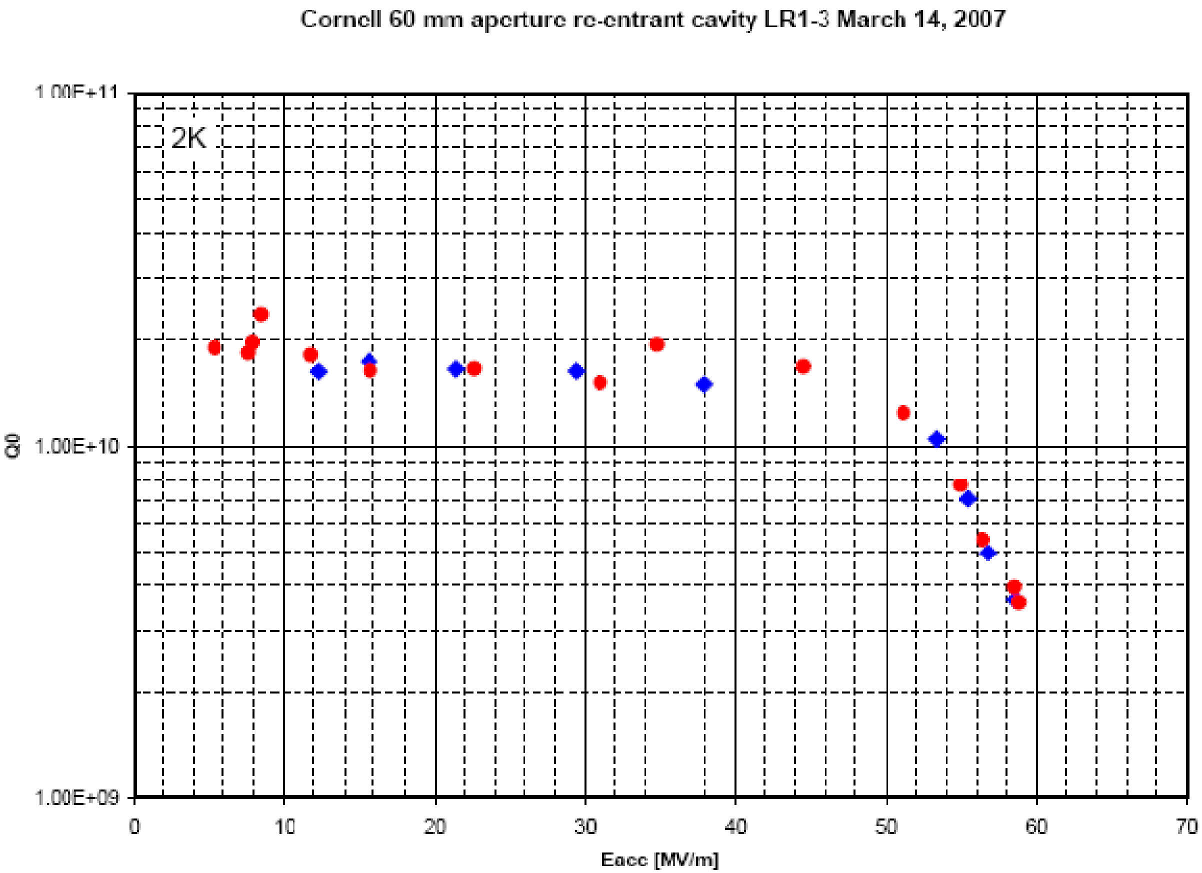
Ave. Eacc=46.7±1.9MV/m

Scattering:4%, Acceptability@40MV/m(ACD):100%

		IS#2	IS#3	IS#4	IS#6	IS#7	CLG#1
+EP(20+3) +HF*	Eacc	47.07	44.67*	47.82	48.60*	43.93*	47.90*
	Qo	1.06e10	0.98e10	0.78e10	0.80e10	1.17e10	1.0e10

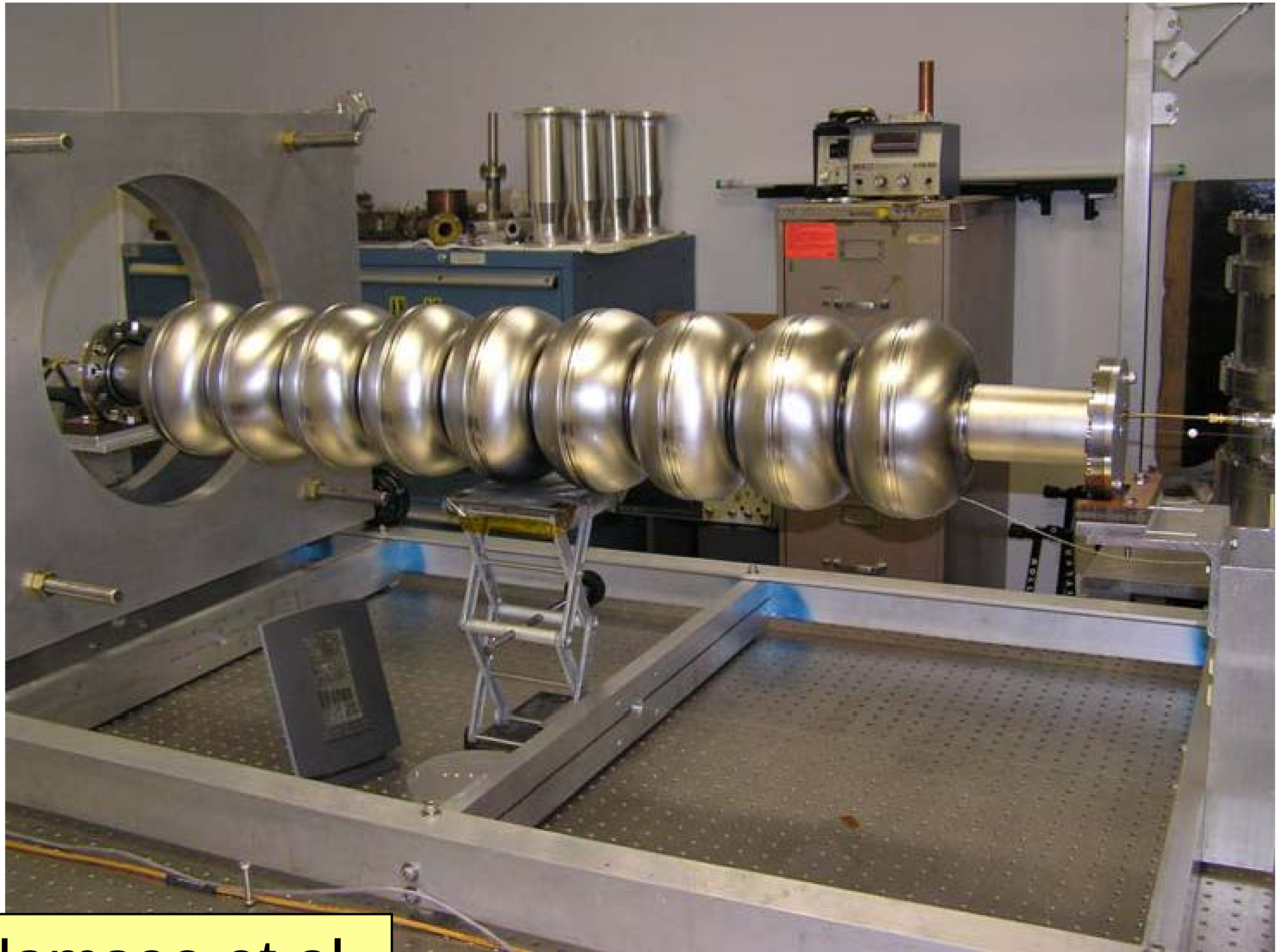
60mm-Aperture Re-Entrant Cavity
Best Eacc = 59 MV/m
Cornell-KEK Collaboration

H. Padamsee et al.



RE-LR1-3

ACD: AES (Medford, NY)
Built and Tuned 9-cell Re-Entrant Cavity (70 mm aperture)



H. Padamsee et al.

S0S1 Plan is on the Move

- Dedicated manpower added to task force
- R&D with many results closely linked to this plan are available already
  - **E.g. the XFEL project is an important stepping stone with several important results for the ILC**
- Tight-loop started
  - **Hot candidates for surface preparation:**
    - Fresh acid, H202, Ultrasound degrease
  - **Common data sets are being developed**
- Production-like
  - **Resource-intensive**
  - **Several batches are underway**
  - **Facilities are becoming online (Jlab, STF coming next)**
- Modules
  - **M6 and M7 are important data points**
  - **Resource-intensive and long lead times**
    - Under discussion: Propose to build proof-of-principle across regions
  - **Interface to S2 needs work**
- S0S1 Plan has become much clearer as resources are known better
  - **Scenarios have been developed**
    - Pessimistic case: A lot of data available for an educated decision for the EDR
    - Optimistic case: Even though the final full production-like assessment will be later than the EDR a significantly improved data set available on ILC-specific process
- XFEL
  - **Several points of connection have been discussed and are critical to the success of the ILC R&D program**
- Alternatives are developing rapidly

XFEL is an Important Asset

- Continuous production of cavities in line of preparation improvements
  - **XFEL is a significant part of the cavity data set, as you have seen**
- Material issues
  - **Scanning for a large batch of material**
  - **Qualifying more niobium vendors**
  - **Alternatives: Large-grain material is still an option for the XFEL**
- Pre-series will start 2008
  - **EP is becoming industry process from autumn**
- Design for manufacturing for the cavities
  - **Review types of welds and welding procedures**
- Quality assurance
  - **Defining a reasonable and affordable QC procedure**
- Module design and assembly has been reviewed by industry
  - **Report is due soon**
- (Coupler industrialisation)

- Thanks for your attention!