S0S1 Taskforce

High-Gradient SC Cavities

Lutz Lilje

GDE

Outline

- Recapitulation
  - **S0S1 charge**
  - **S0S1 goals**
- Executing the S0S1 Plan
  - **First results**
  - **Further refinements**
  - **Estimation of resources**
- Alternatives (in second part of the talk)

‘S‘-issues: Overview

- S0
  - Achieve **35 MV/m in 9-cell cavity in vertical dewar tests** (low-power) with a sufficient yield
  - Staged approach with intermediate goals to track progress
- S1
  - Achieve **31.5 operational** as specified in the BCD **in more than one accelerating module**
  - … and enough overhead as described in the BCD.
- S2
  - a string of N modules with full xyz...by date ...
  - Need for a linac ?
  - Endurance testing

Gradient Task Force Charge

- The RDB is asked to set up a Task Force to carry out a closely coordinated global execution of the work leading to the achievement of the accelerating gradient specified in the ILC Baseline.
- A definition of the goals for the cavity performance in terms of gradient and yield and a plan for achieving them should be proposed by this group, which should take account of the global resources available and how they may be used most rapidly and efficiently.
- The accelerating gradient performance and yield should be specified both for an individual 9-cell cavity and for an individual cryomodule, and the plan should cover the demonstration of this performance in both cases.
- The GDE will facilitate the coordination at the global level to achieve this vital goal as soon as possible.

S0/S1 Task Force

- Hitoshi Hayano (KEK)
- Toshiyasu Higo (KEK)
- John Mammosser (JLab)
- Hasan Padamsee (Cornell)
- Marc Ross (FNAL)
- Kenji Saito (KEK)
- Lutz Lilje (DESY)

- Added dedicated manpower to the taskforce:
  - **Project engineer for coordination**
    - coordinating cavity exchange, keeping track of tests
    - implementation of standard data sets
    - Phil Pfund (FNAL)
  - **Scientific investigator**
    - data evaluation
    - improve data consistency
    - Camille Ginsburg (FNAL)

Basic Assumptions

- The basic recipe for highest gradients is known: Electropolishing, High Pressure Water Rinse and In-situ Bakeout
  - Results are not fully reproducible
  - Field emission is a major problem
  - Some contaminants have been identified
- Fine-tuning the surface preparation parameters is needed
  - Need to separate the surface preparation process from the potential fabrication errors by new vendors
- Need to get a statistically meaningful sample for the overall cavity fabrication and preparation
  - Large number of cavities from several regions in a production-like mode eventually

S0 Ultimate Goals

- The cavity performance is influenced by the fabrication process and surface preparation process.
  - **Effort in all the regions to qualify further vendors for cavities**
- Preparation process and vertical test yield for 35 MV/m at $Q_0 = 10^{10}$ should be greater than 90% for a sufficiently large number (greater than 100) of preparation and test cycles.
  - **There should be a complete description of the preparation and testing processes (reproducibility in other places). The time scale should be commensurate with the completion of the EDR (middle of 2009).**

S0 Ultimate Goals

- After a viable cavity process has been determined through a series of preparations and vertical tests on a significant number of cavities, achieve 35 MV/m at $Q_0 = 10^{10}$ in a sufficiently large final sample (greater than 30) of nine-cell cavities in the low-power vertical dewar testing in a production-like operation e.g. all cavities get the same treatment.
  - **The yield for the number of successful cavities of the final production batch should be larger than 80% in the first test. After re-processing the 20 % underperforming cavities the yield should go up to 95%. This is consistent with the assumption in the RDR costing exercise.**

S1 Ultimate Goals

- Final goal (following the BCD definition):
  - **Achieve 31.5 MV/m at a $Q_0=10^{10}$ as operational gradient as specified in the BCD in more than one module of 8 cavities including e.g. fast tuner operation and other features that could affect gradient performance**
  - **All cavities built into modules perform at 31.5 MV/m including enough overhead as described in the BCD. The cavities accepted in the low-power test should achieve 35 MV/m at $Q_0 = 10^{10}$ with a yield as described in the S0 definition (80% after first test, 95% after re-preparation).**
  - **At least three modules should achieve this performance. This could include re-assemblies of cryostats (e.g. exchange of cavities).**
  - **It does not need to be final module design. An operation for a few weeks should be performed.**
- Intermediate goal
  - **Achieve 31.5 MV/m average operational accelerating gradient in a single cryomodule as a proof-of- existence. In case of cavities performing below the average, this could be achieved by tweaking the RF distribution accordingly.**

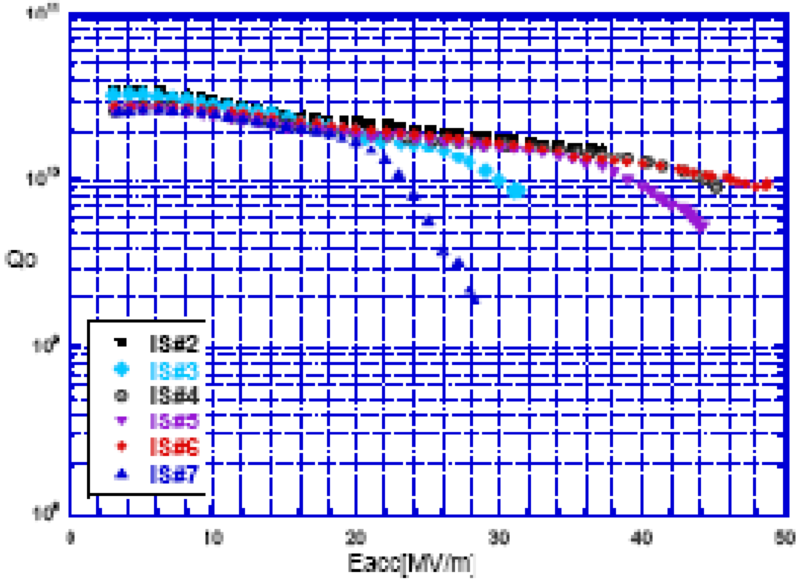
S0S1 'Tight-Loop': Improvement of the Cavity Preparation Process

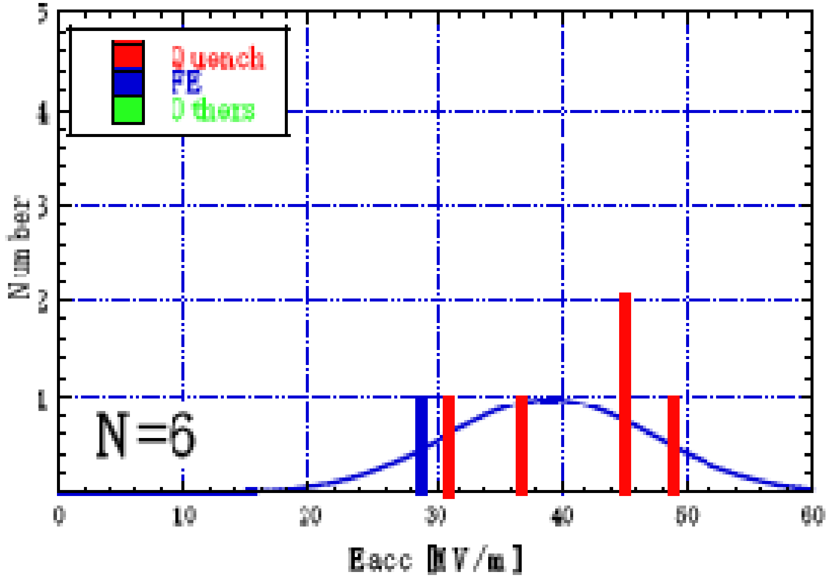
- Basic assumptions
  - **Preparation is the critical step**
- Main goal:
  - **Demonstrate 80% yield in first acceptance test, then 95% with second try**
- Tight-loop
  - **Test minor variations in the final surface preparation**
    - Conduct a dedicated single-cell program
    - cavity exchange
  - **Demonstrate multi-cell handling**
  - **Compare regional preparation setup performance**
  - **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 H2O2

S0-Single cell study @ KEK

	Eacc, max[MV/m] / Qo@Eacc max								Ave.Eacc
recipe	IS#2	IS#3	IS#4	IS#5	IS#6	IS#7	CLG#1	CLG#2	
(A) CBP+CP+AN +EP(80) +HPR+Bake	36.90	31.40	45.10	44.20	48.80	28.30			39.1±8.2
	1.53e10	8.66e9	9.07e9	5.38e9	9.64e9	1.94e9			
(B) CBP+CP+AN +EP(80+3)+HF +HPR+Bake		42.00	46.10	44.70	34.25	39.30		43.80	41.7±4.4
		9.72e9	9.47e9	1.08e10	8.56e9	1.03e10		3.46e9	
(C) +EP(20) +HPR+Bake	47.24	52.44	52.91	31.10	48.92	46.54			46.5 ±8.0
	5.98e9	1.51e10	5.23e9	5.21e9	7.56e9	9.03e9			
(D) +EP(20+3)+HF* +HPR+Bake	47.07	44.67*	47.82		48.60*	43.93*	47.90*		46.7 ±1.9
	1.06e10	0.98e10	0.78e10		0.80e10	1.17e10	1.0e10		
(E) +EP(20)+H_2O_2 +HPR+Bake	Now on going								
(F) +EP(20)+Degrease +HPR+Bake									

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



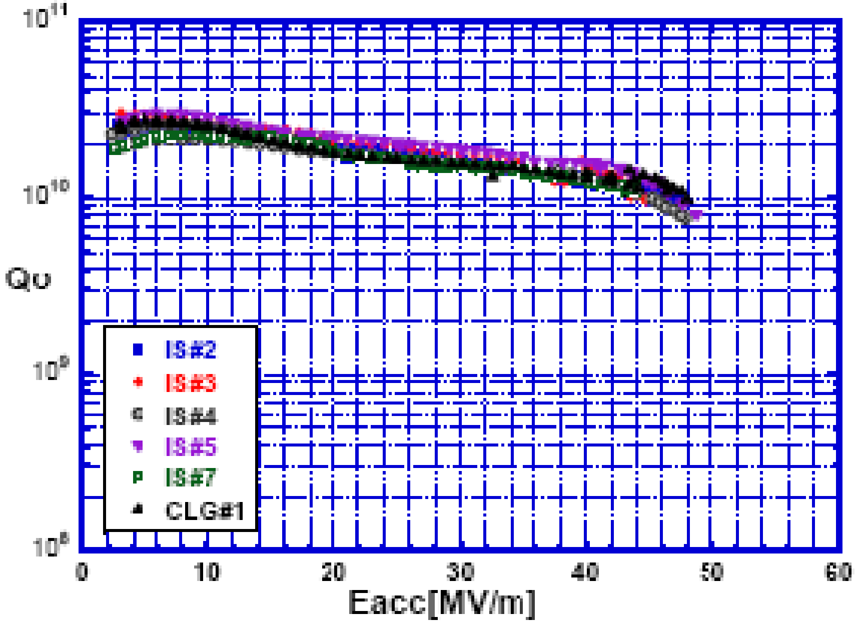


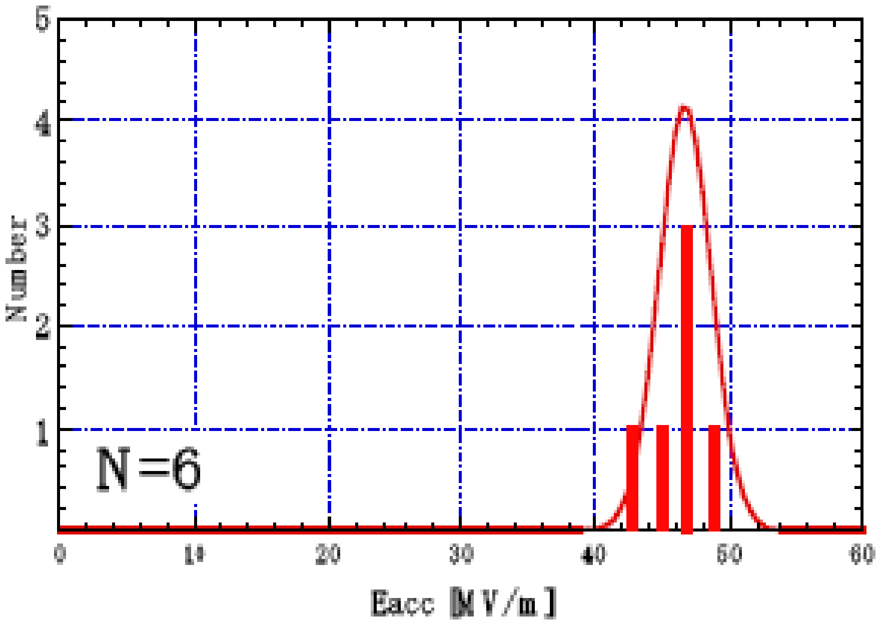
Ave. Eacc=39.1±8.2MV/m

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)





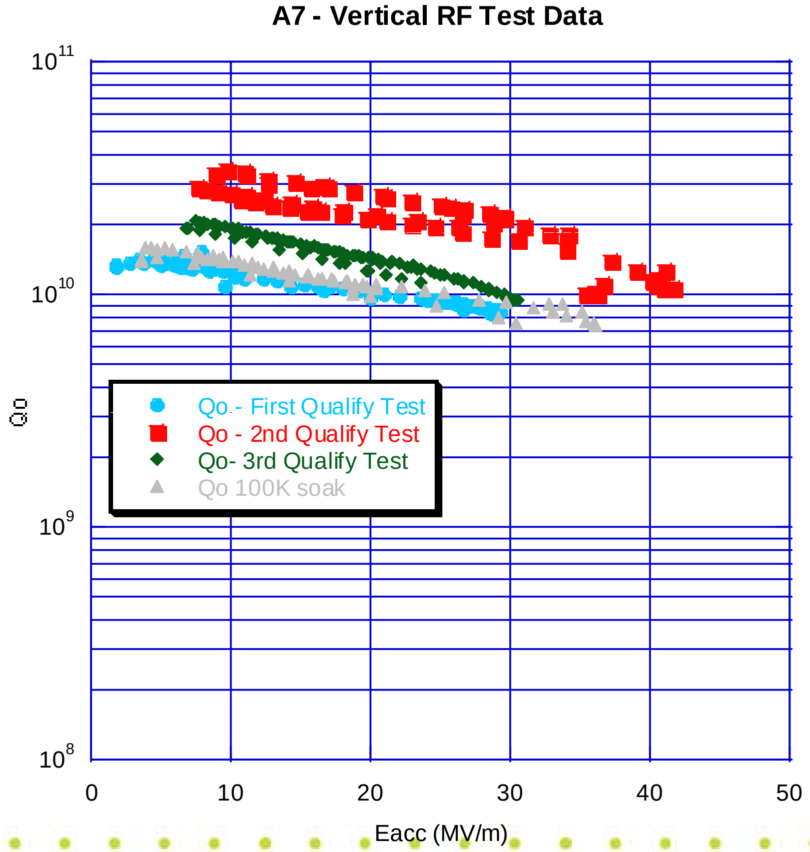
Ave. Eacc=46.7±1.9MV/m

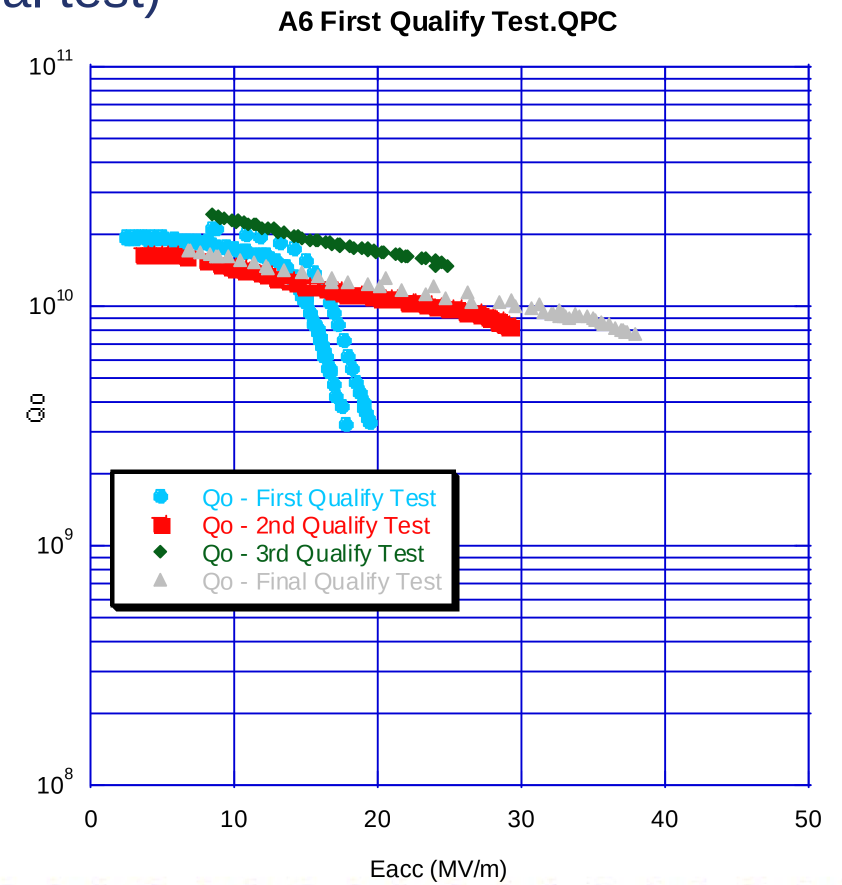
Scattering:4%, Acceptability@40MV/m(ACD):100%

		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

JLab Multi-Cells

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





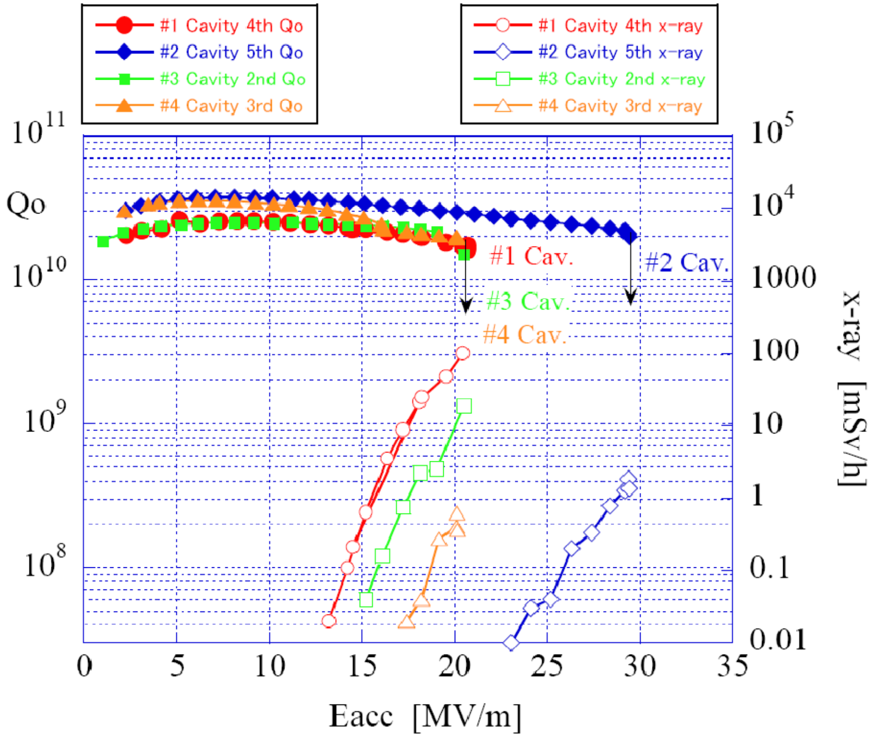
S0S1 ‘Production-like’: Determine the Yield of the Full Production Chain

- 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
  - **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
  - **Update on Statistics**

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

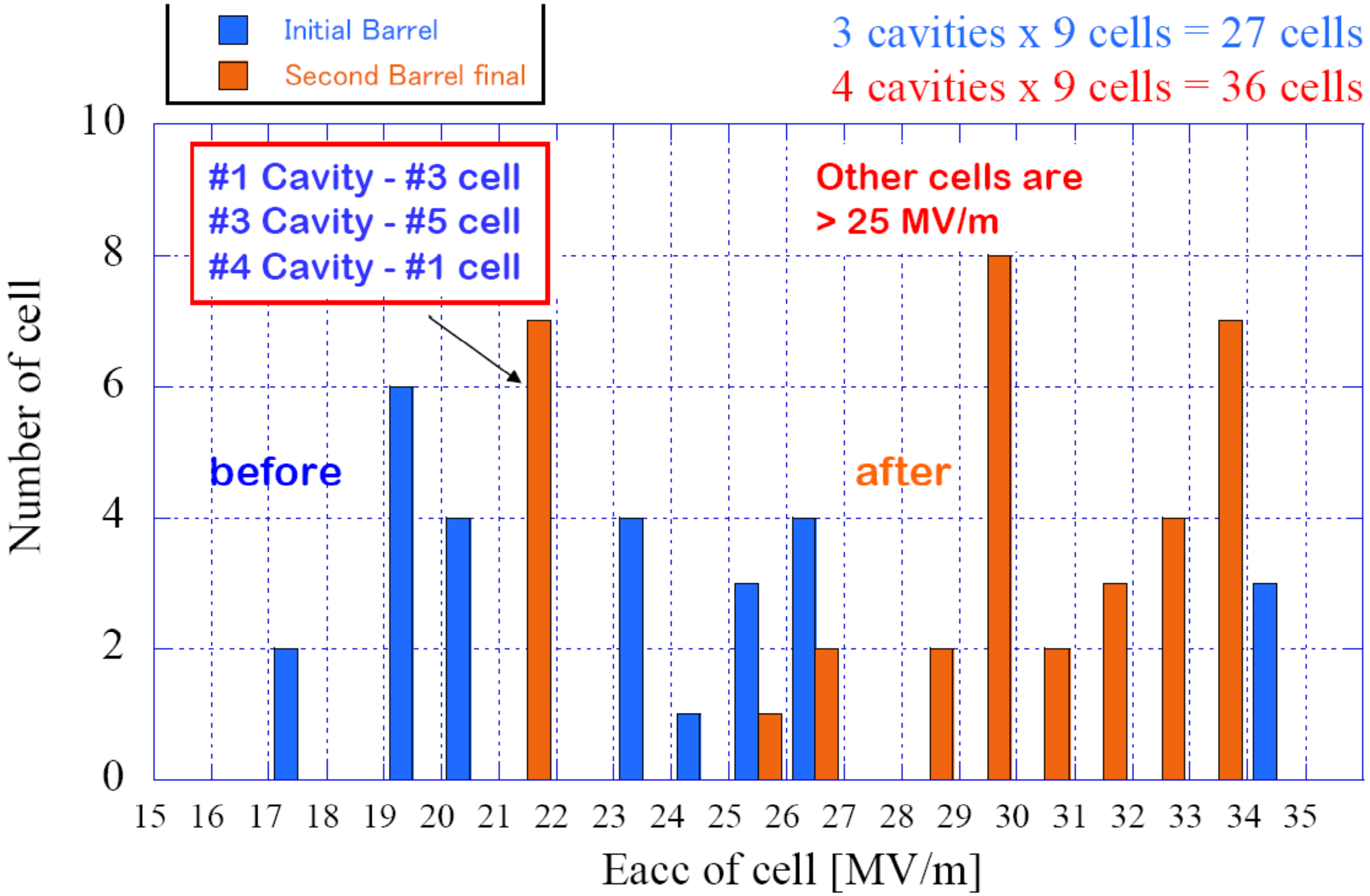
#4 20.2 MV/m

high Qo > 10^{10}

- New cavity vendor
- Surface treatment at ‘standard‘ company
- Results
  - **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)



E. Kako (KEK)

TTC Meeting at FNAL
2007. Apr. 25

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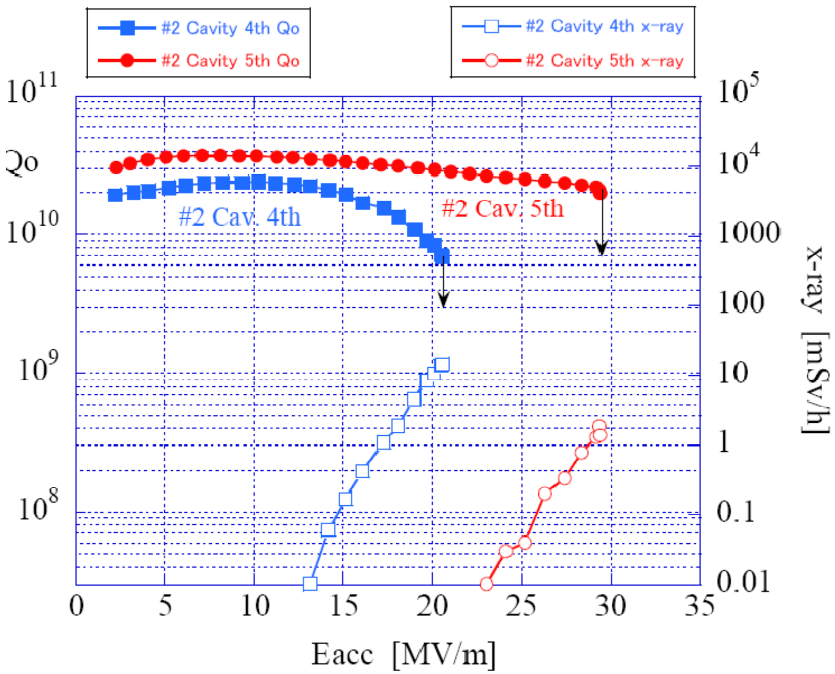
KEK TESLA-type: 3rd Alternative Rinse

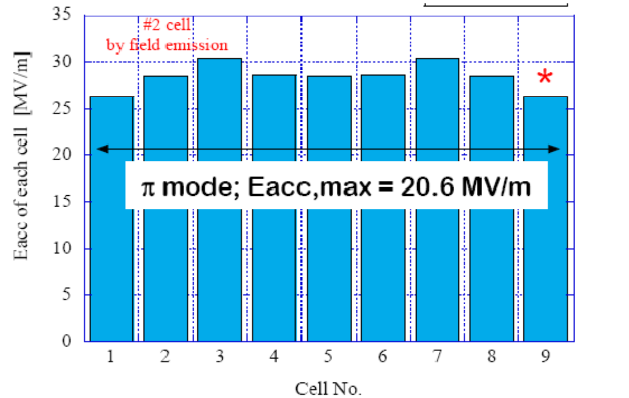
Vertical Test Results, #2 Cavity

#2 Cavity ; 4th and 5th Test

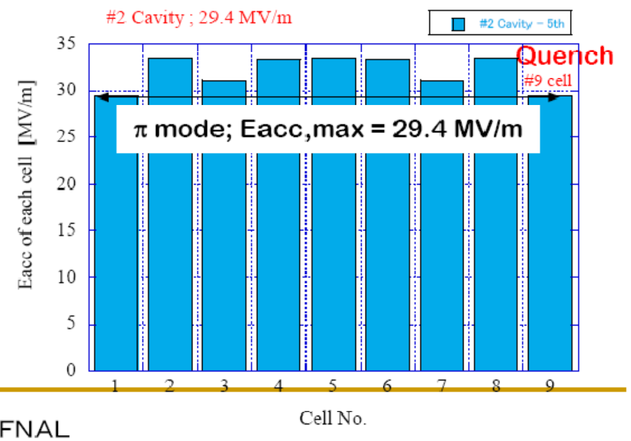
+ EP 20μm, H_2O_2 Rinse 1h, Hot Rinse 1h, HPR 16h



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



#2 Cav. 5th



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TTC Meeting at FNAL
2007. Apr. 25

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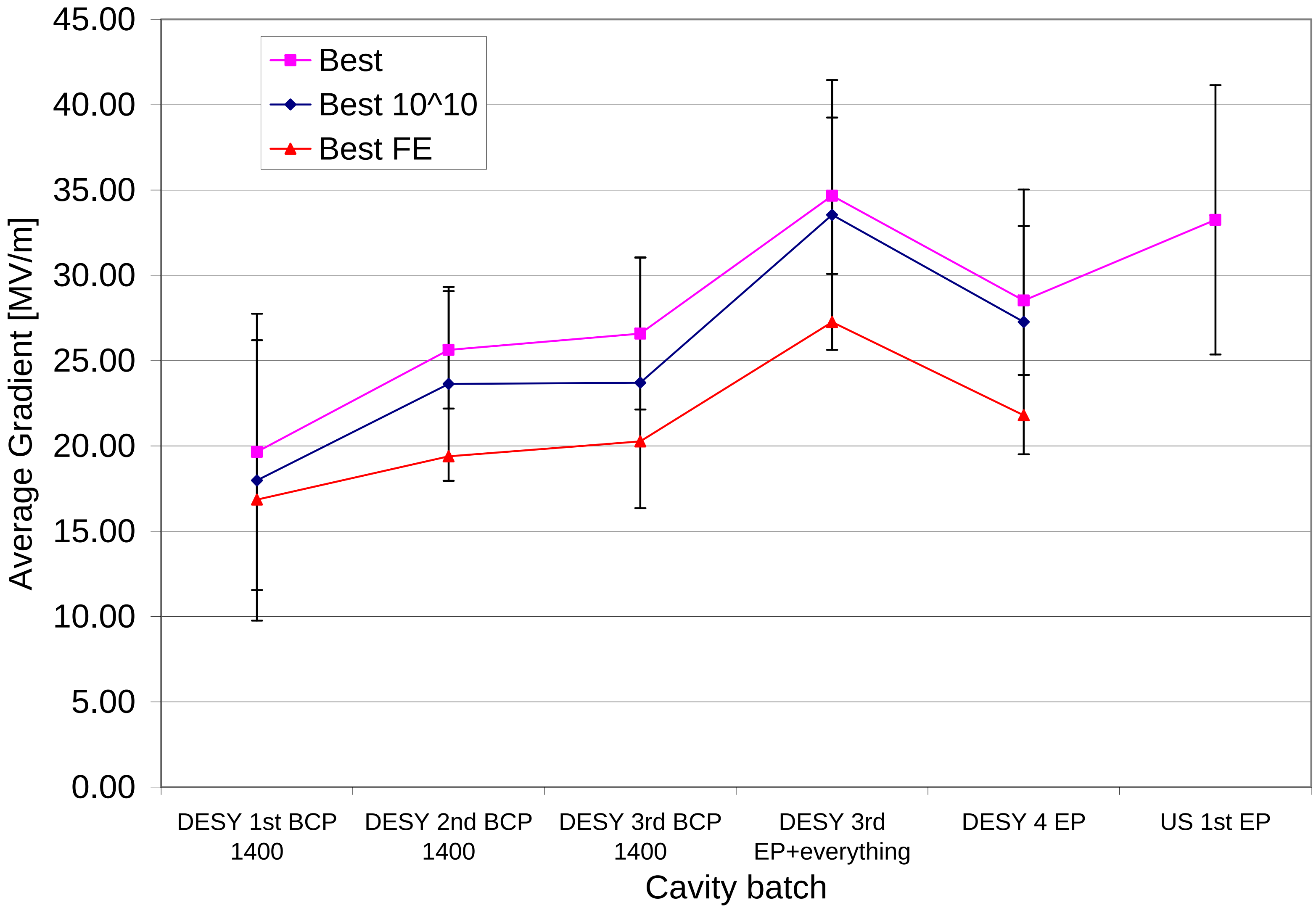
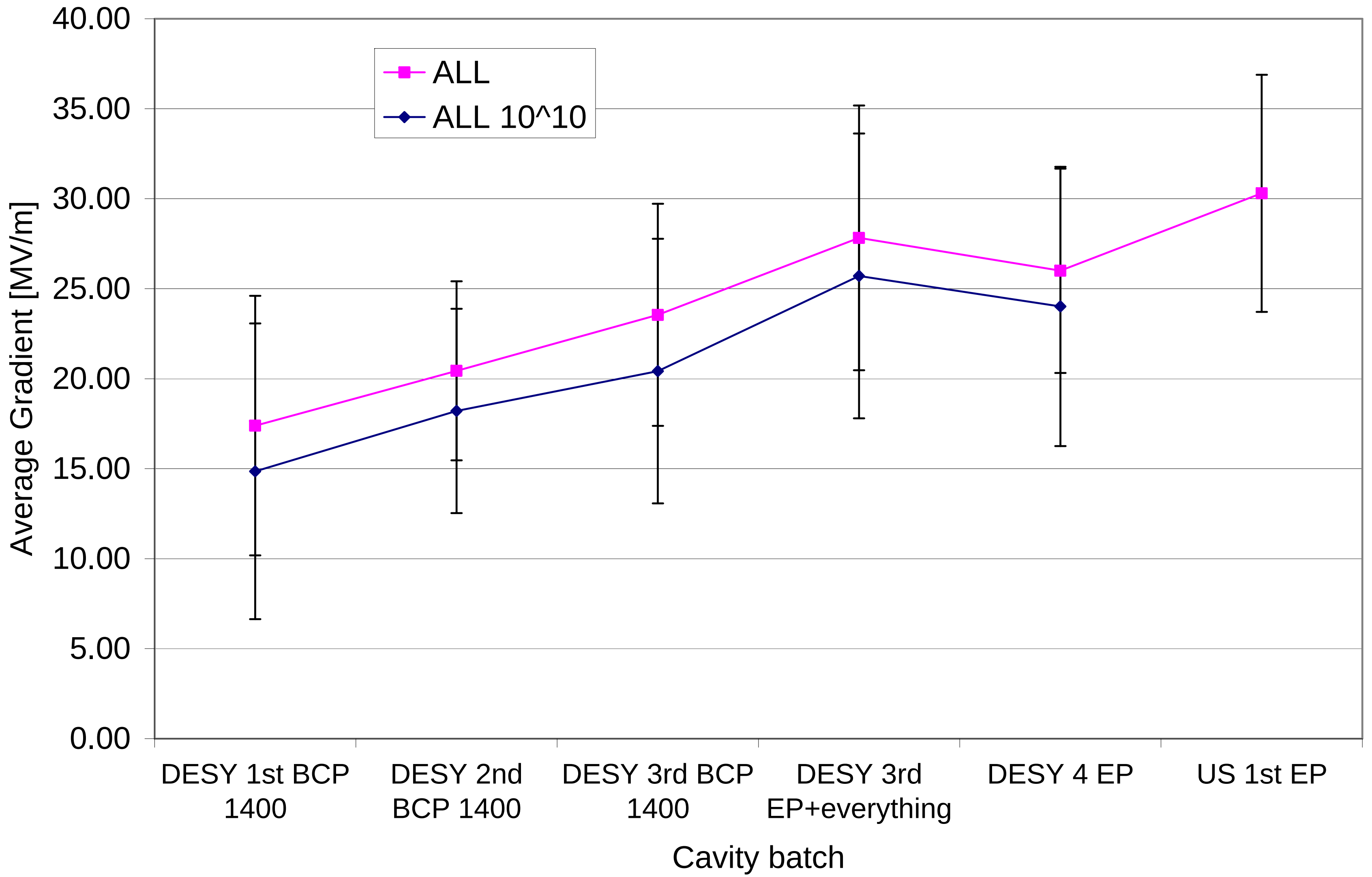
Comparison of Qualified Vendors: DESY and US Data

- 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
      - Left out tests with etch

‘Qualified’ Vendor Productions: Best Test Results



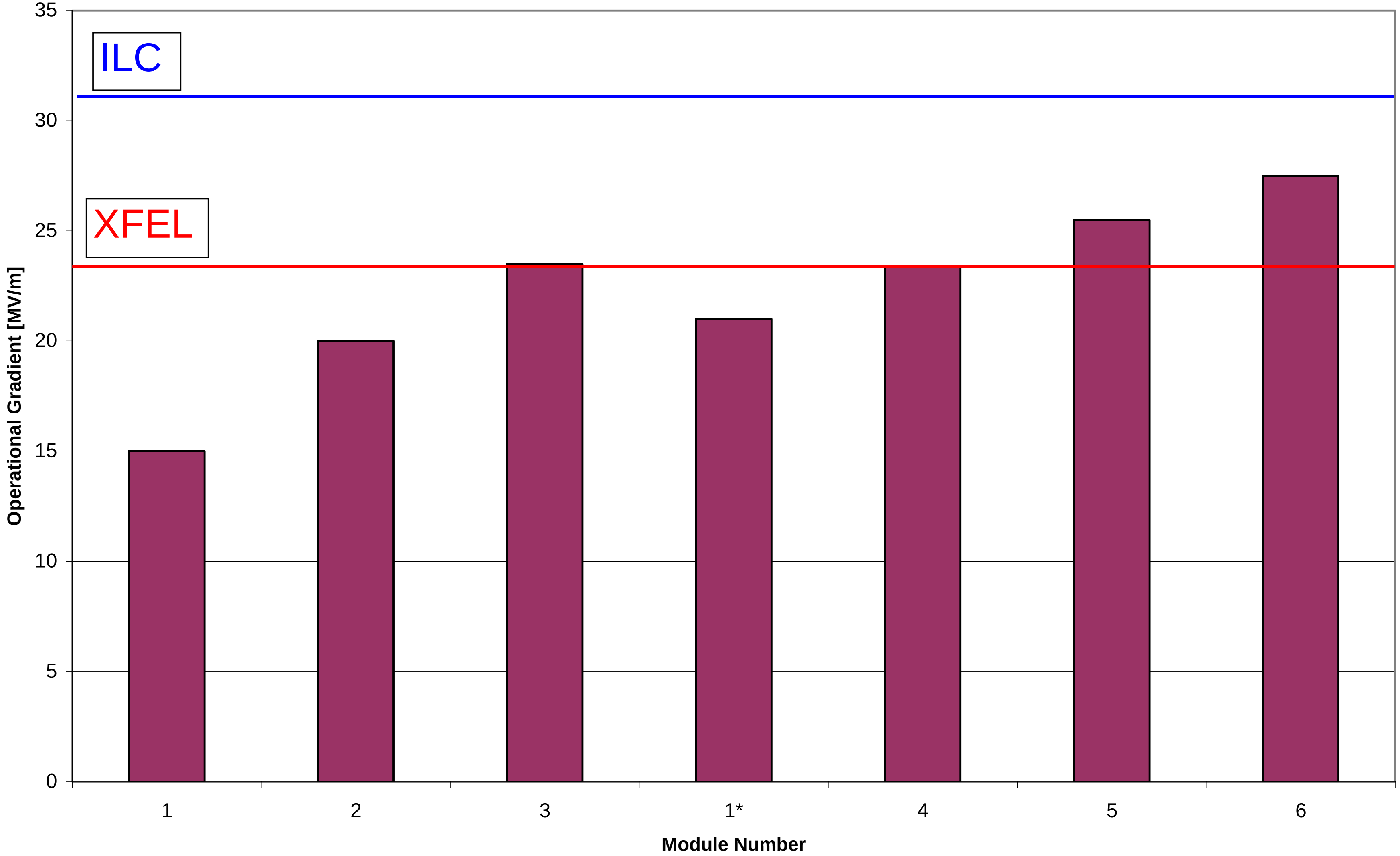
‘Qualified’ Vendor Productions: All Test Results



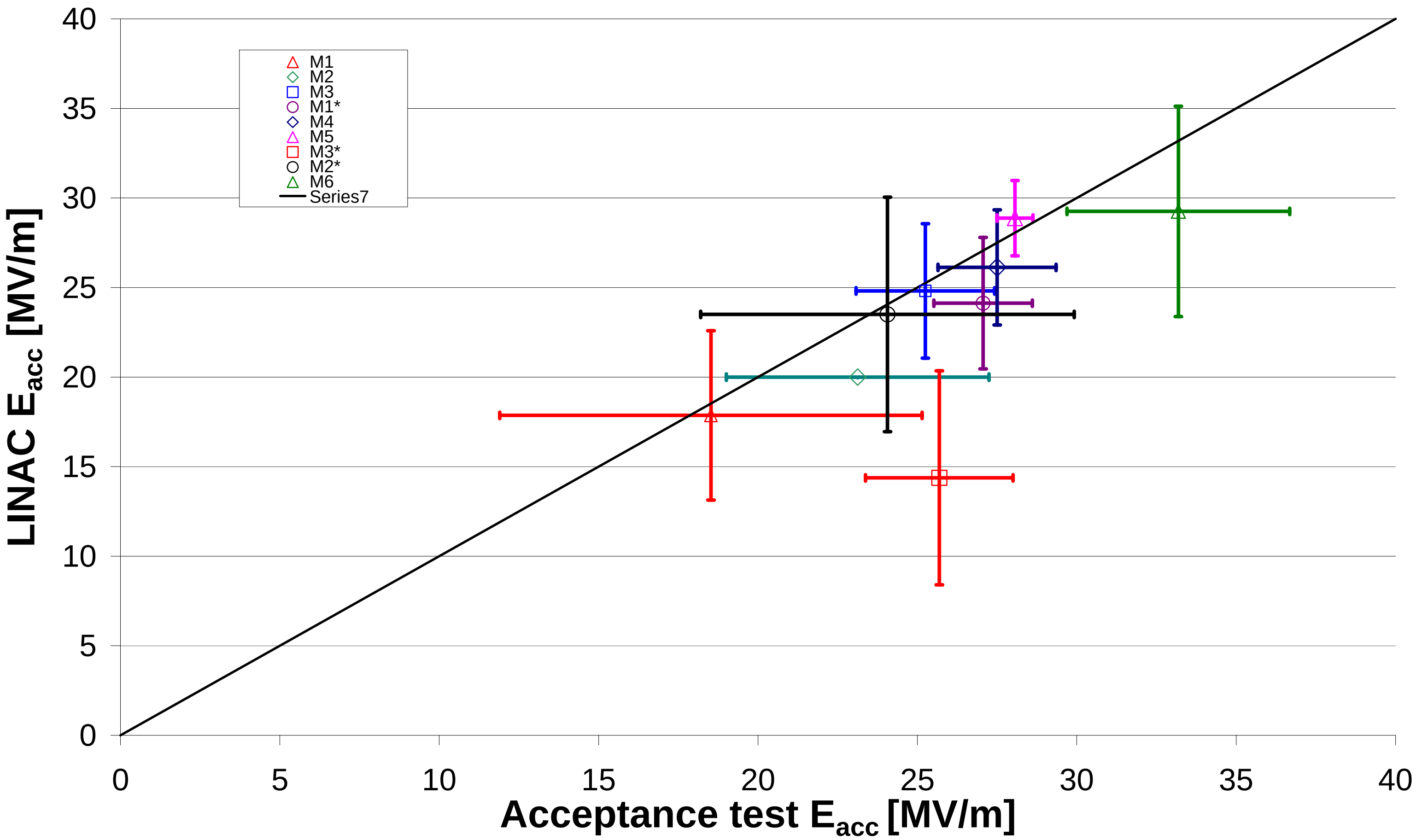
S1

- Module tests
  - **History of earlier modules**
    - The acceptance test 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
    - M4 and M5 both much closer agreement between VTA and module performance
  - **M6**
    - Gradient aimed at ILC specification
    - Test also
      - Couplers
      - Tuners
      - Thermal cycling
      - Vibration studies
    - FLASH module
      - Schedule pressure determined final choice of cavities
        - » Compromises made for gradient performance
  - **M7**
    - Preliminary data!

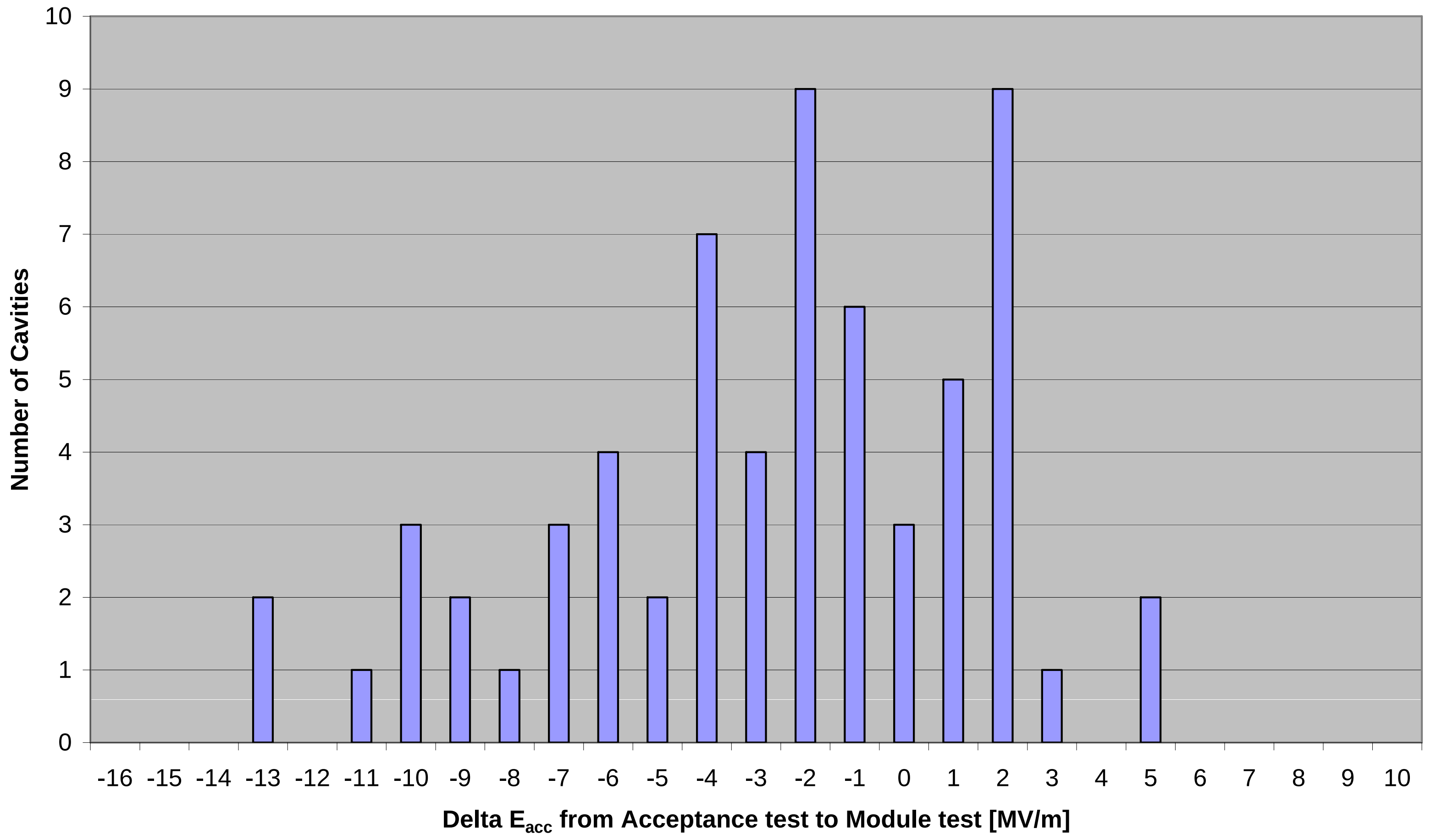
Accelerator Module Operational Gradients



LINAC vs. Vertical (Cavity Average Gradients)



Compare Acceptance Test with Module Operational Accelerating Gradient



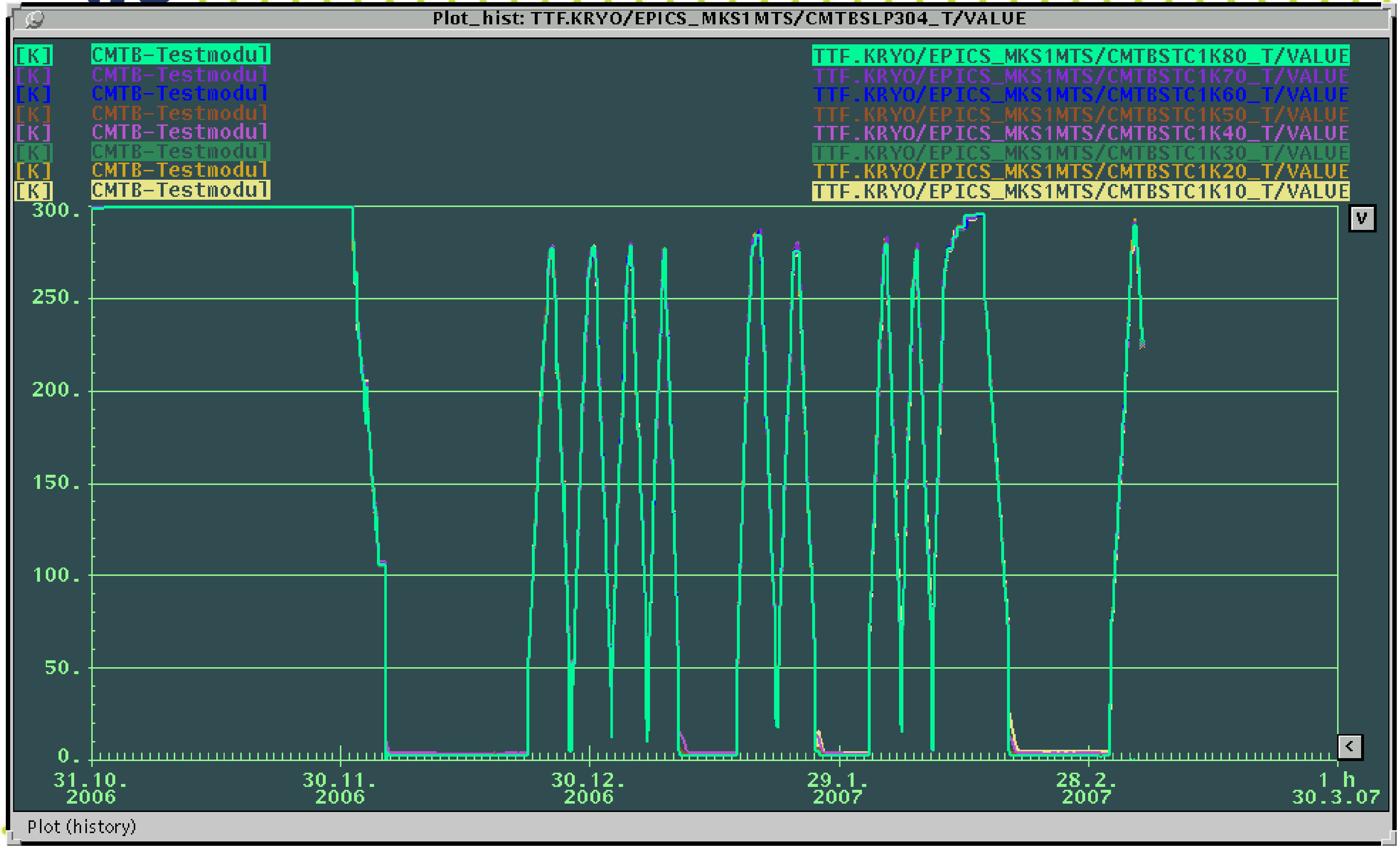
Module Test at DESY

- A high gradient module has been assembled
- Test in dedicated test stand possible e.g.
  - **Thermal cycles**
  - **Heat loads**
  - **Cavity performance**
  - **Coupler conditioning**
  - **Fast tuner performance**
  - **(LLRF tests)**

CMTB Module 6 during 11th cool down

Status:06-March-07

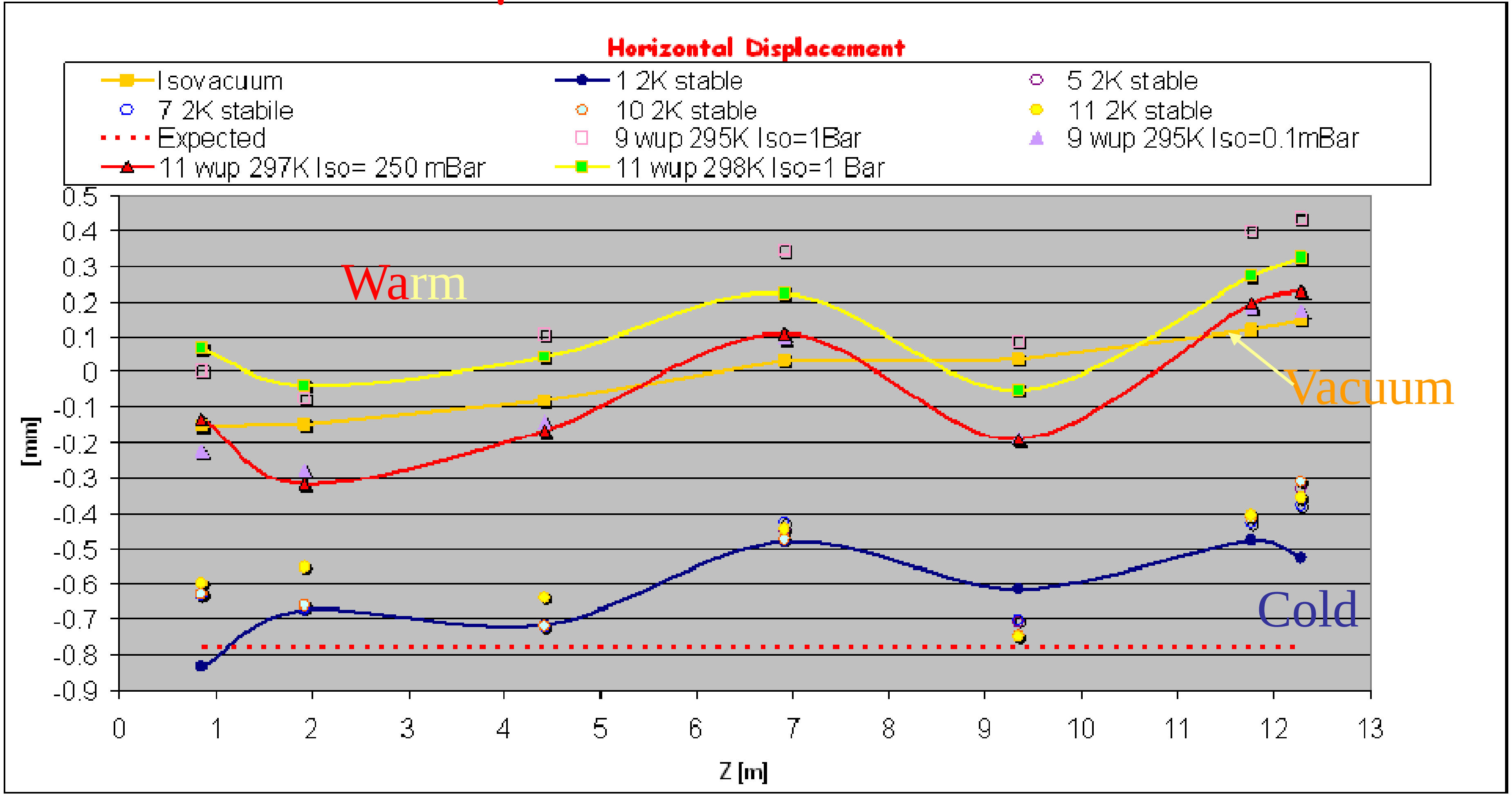
R. Lange



Cryogenic and Alignment tests

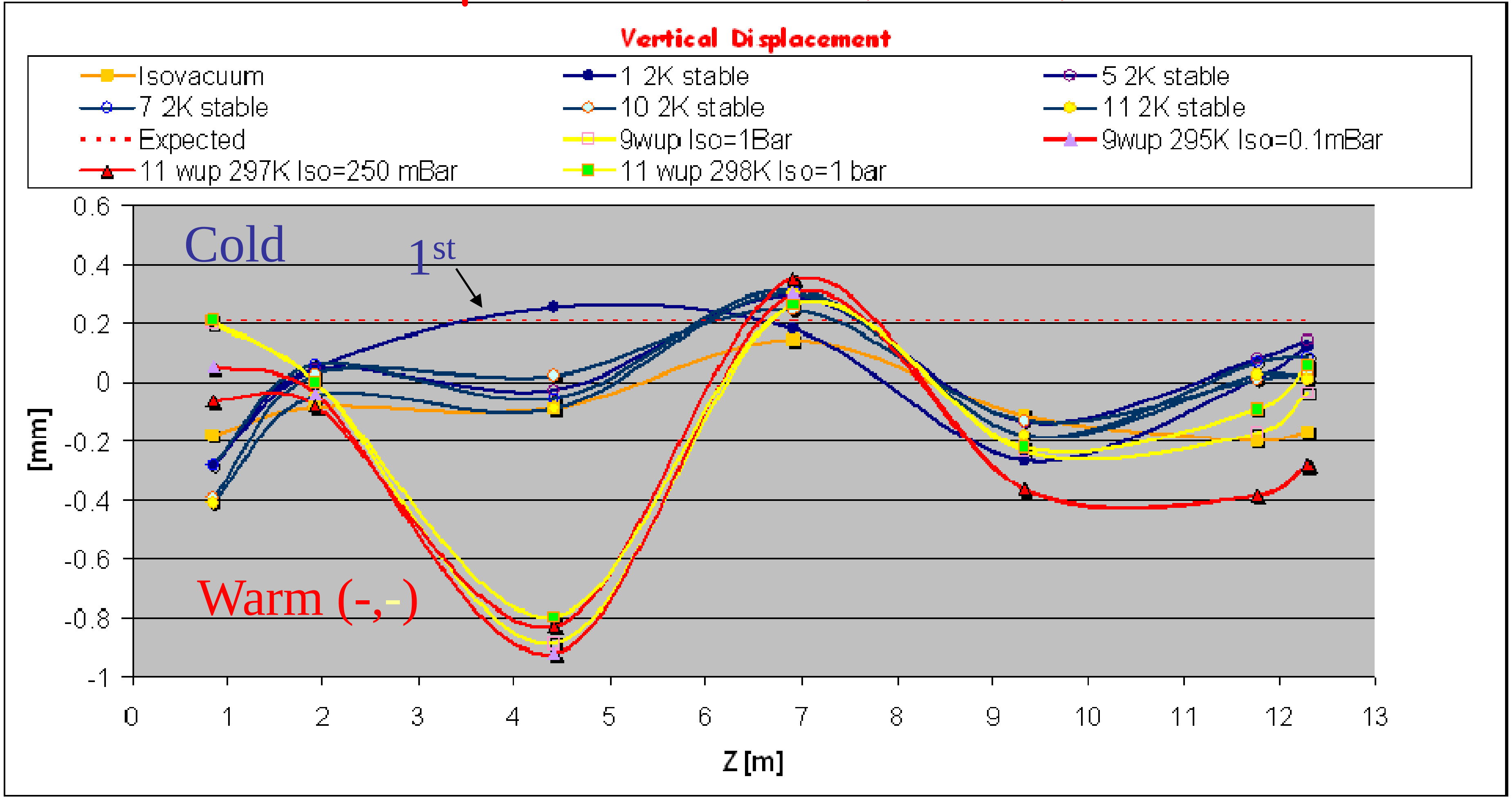
- TTF type 3 module
  - **Heat load static (expected value)**
    - 40 /80 K: 80 Watt +/- 5 (75 Watt)
    - 4 K: 13 Watt +/- 2 (13 Watt)
    - 2 K: 3.5 Watt +/-1.5 (2.8 Watt)
    - Note: 2 Endcaps lead to higher loss!
  - **Module dynamic losses 20 / 22 / 25 MV/m**
    - 40 /80 K:20.9 / 22.5 / 24.3 Watt (~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**

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



A. Bosotti

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

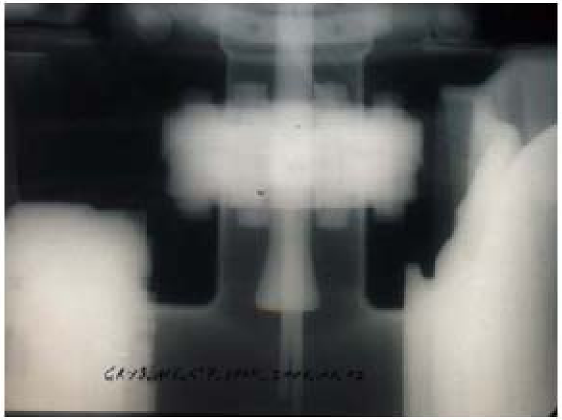


A. Bosotti

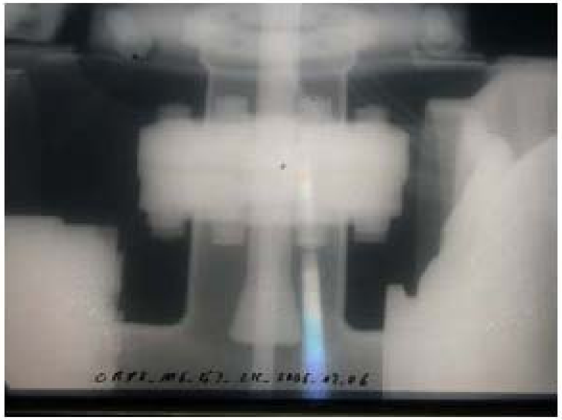
Longitudinal Position: Xray of Coupler Antenna (C7)

(Ansicht Y-Achse)

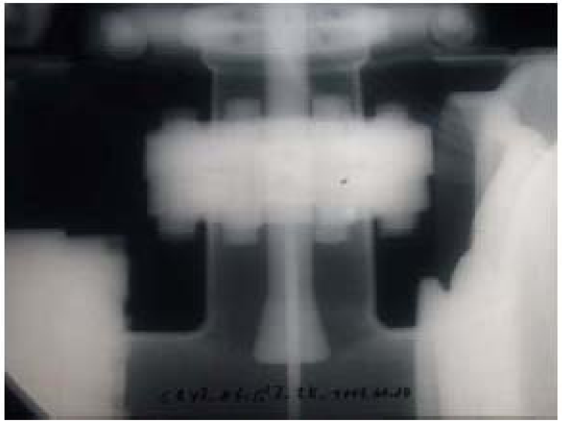
300 K vor
1 therm.
Zyklus



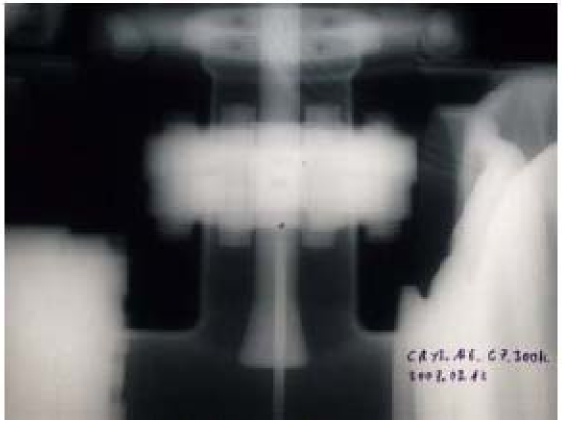
2 K nach
1 therm.
Zyklus



2 K nach
5 therm.
Zyklus



300 K nach
11 therm.
Zyklus



← Beam direction

K. Jensch

The experiment – Setup

Vessel top vertical sensor (horizontal transverse companion not visible)

Ground vertical sensor (horizontal transverse companion not visible)

$x(t),\ y(t)$	time series of length T, N points each
$X(\nu_i),\ Y(\nu_i)$	FFT
$\langle XX^*\rangle,\ \langle YY^*\rangle$	Estimated dispacement power specral density (PSD)
$\frac{\lvert\langle XY^*\rangle\rvert^2}{\langle XX^*\rangle\langle YY^*\rangle}$	Coherence
$\sqrt{\frac{\lvert\langle XY^*\rangle\rvert}{\langle XX^*\rangle}}$	Transfer function amplitude
$\sqrt{\frac{1}{T}\sum_{i=k}^{N/2}\langle XX^*\rangle(\nu_i)}$	Integrated RMS amplitude at frequency ν_k

Some definitions

Test amplifier

Cold/warm Geophone — 20 m cable — preamp — Inverse filter — 24 bit Güralp digitizer — Laptop

$$\frac{\omega_0^2 - \omega^2 + i\frac{\omega\omega_0}{Q_0}}{\omega_1^2 - \omega^2 + i\frac{\omega\omega_1}{Q_1}}$$

preamp

Inverse filter

200 S/s

Laptop
Data logging
Spectral analysis (FFT, PSD, Coherence, RMS, Transfer function, etc.)

Inverse filtering provides equalization of the geophone response down to 0.35 Hz

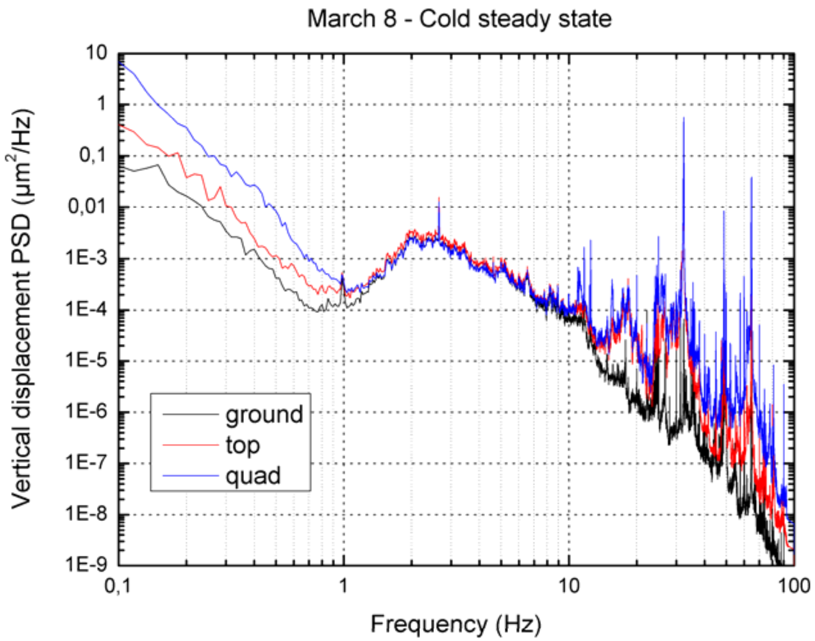
A. Bertolini

Summary of the results (from March 20th meeting)

Our results on Module 6 agree with the piezo data (taken during the 1-9th thermal cycles) at frequencies >10 Hz; geophones allow us to push the measurement down to 1 Hz or even below (important for XFEL and ILC linacs)

Quad vibration level seems not affected at all by the RF operation. No differences have been found between no RF/LLRF/high gradient conditions.

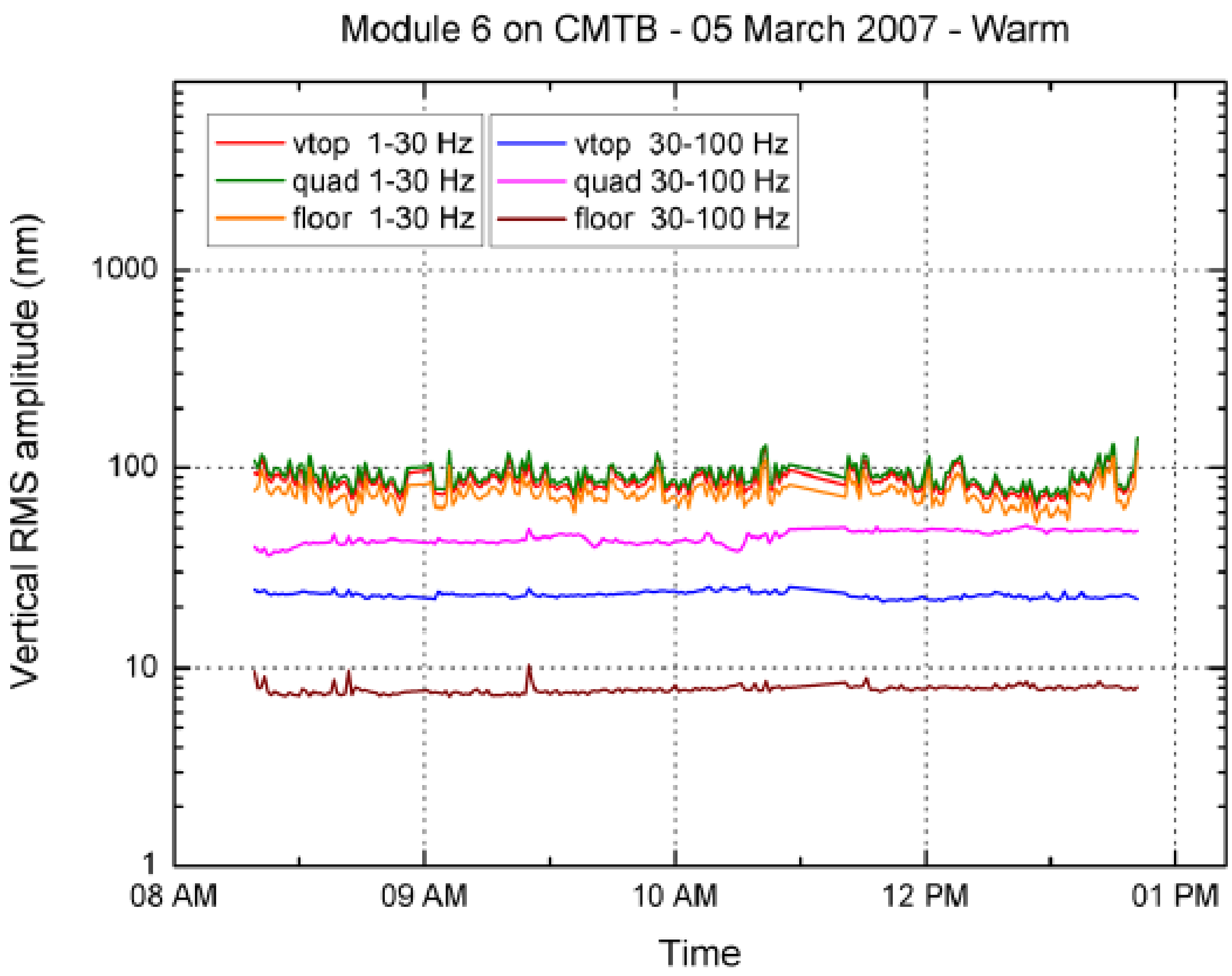
Quad vibration level is not affected by the refrigeration system; no difference with warm operation except for a large amplitude ~30 Hz oscillation (+harmonics) that build up in the cold. Not a mechanical resonance of the cold mass/quad structure: no trace in the transfer function measured at room temperature. For ex. Vertical RMS amplitudes ranging from 200 nm to >1 μm have been measured.



R.Amirikas, A. Bertolini, W. Bialowons, M. Kubczigk

RMS analysis

In the low frequency band the quadrupole motion tracks the ground vibration level. Slight amplitude differences are related mainly to the mechanical transfer function of the module on its support system. Non perfect equalization of the sensor response can also affect the accuracy. Quad RMS overestimated because of the low resonant frequency (4.14 Hz) of this geophone at room temperature.

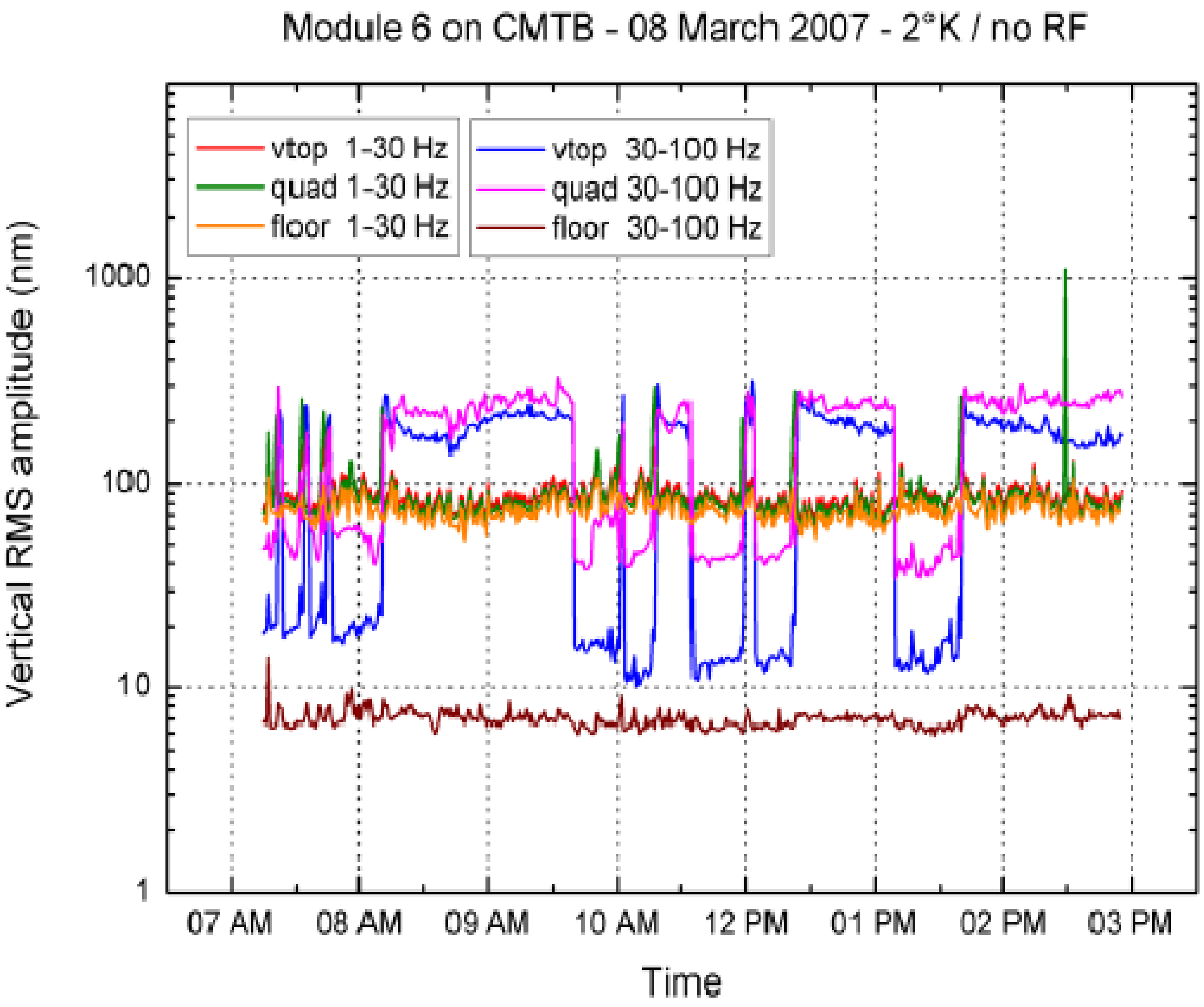


A. Bertolini

Quadrupole vibrations – Cold steady state – no RF

RMS analysis

Ground motion tracking confirmed at low frequencies, with ~10% quad/gnd and top/gnd rms ratios. Large vibration amplitude at high frequency from the CMTB cryogenic plant. The refrigeration system doesn't affect the quadrupole stability at low frequency (f<30 Hz). High frequency noise to be checked after the solution of CMTB cryoplant problems.



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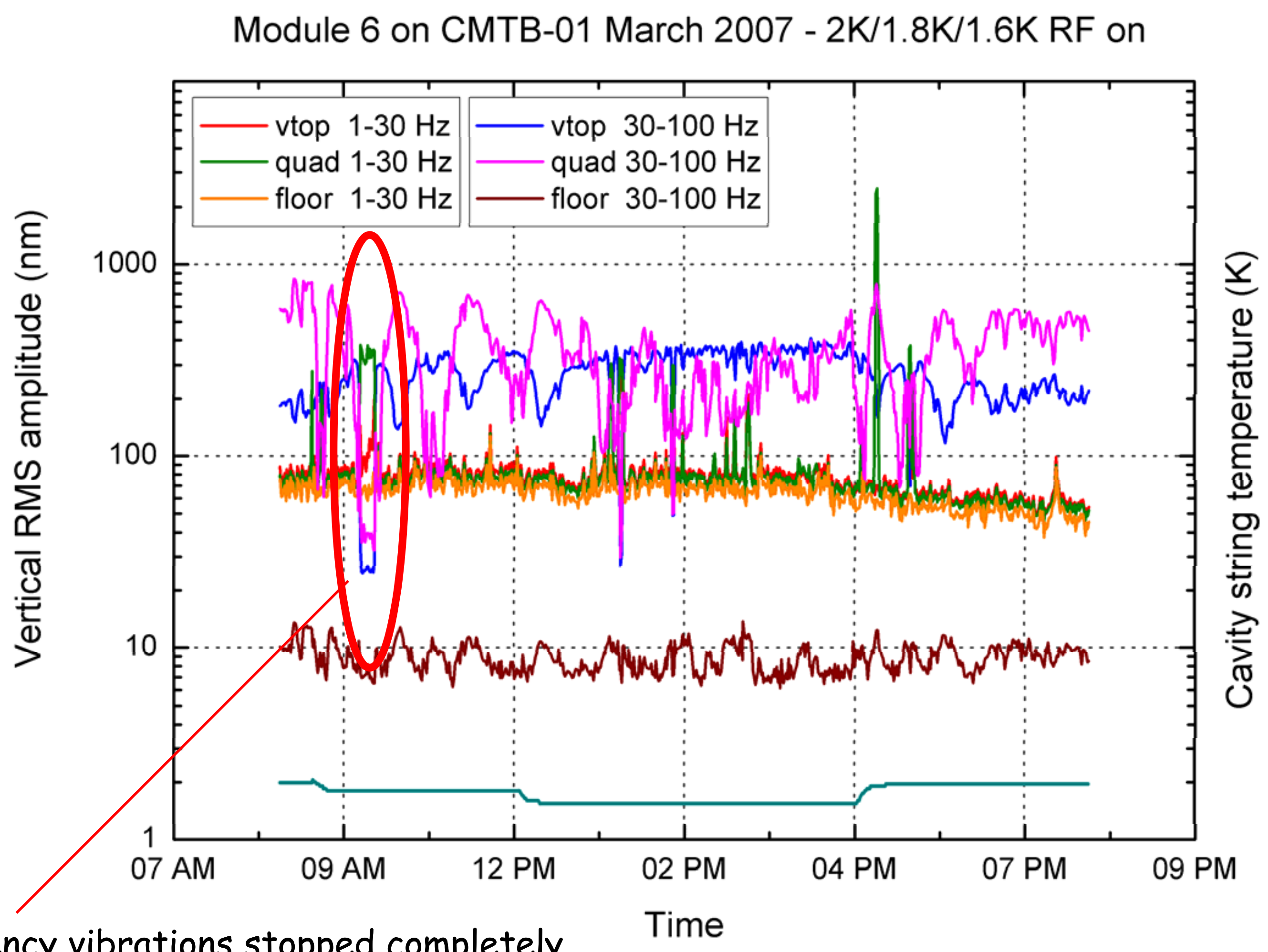
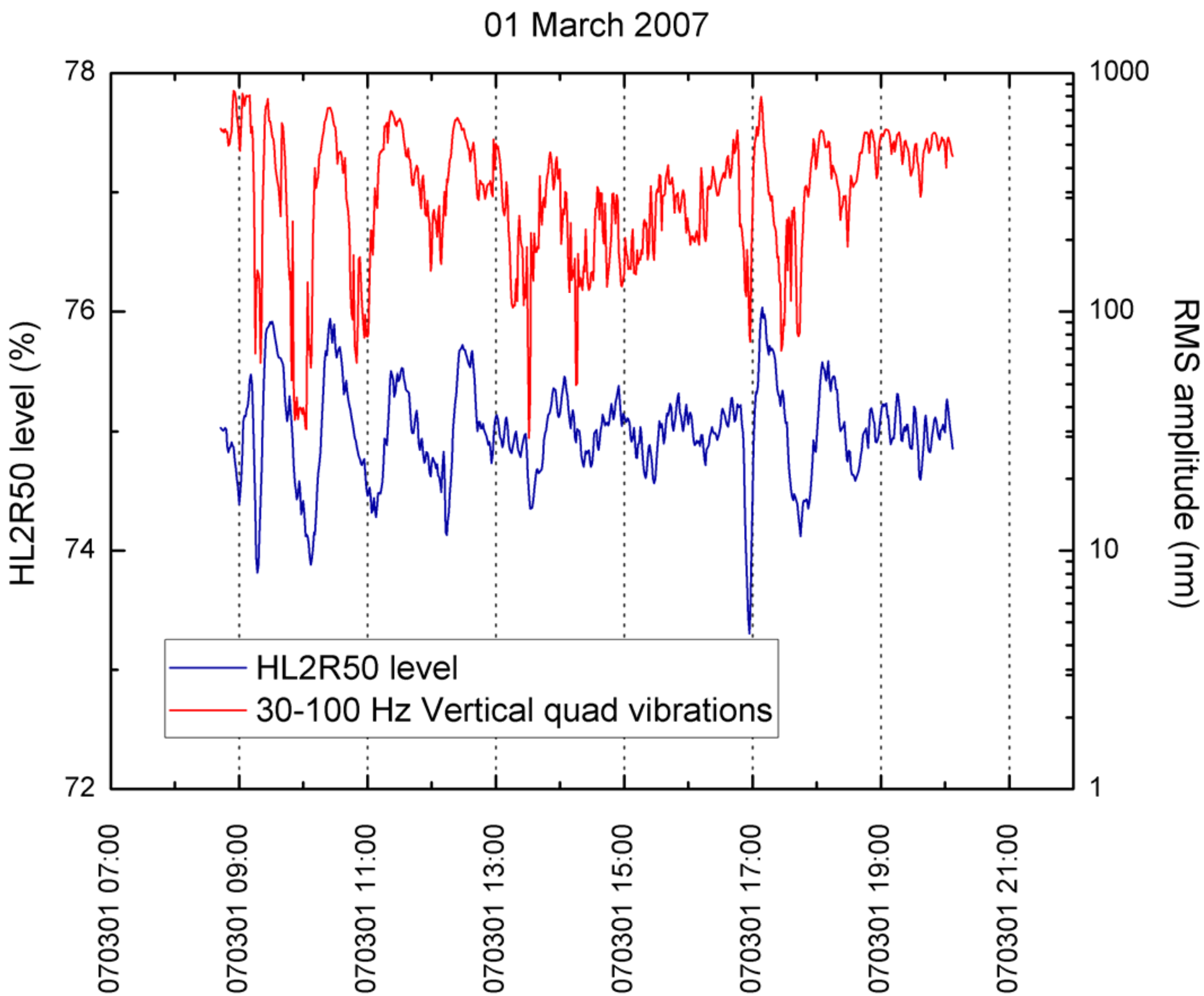
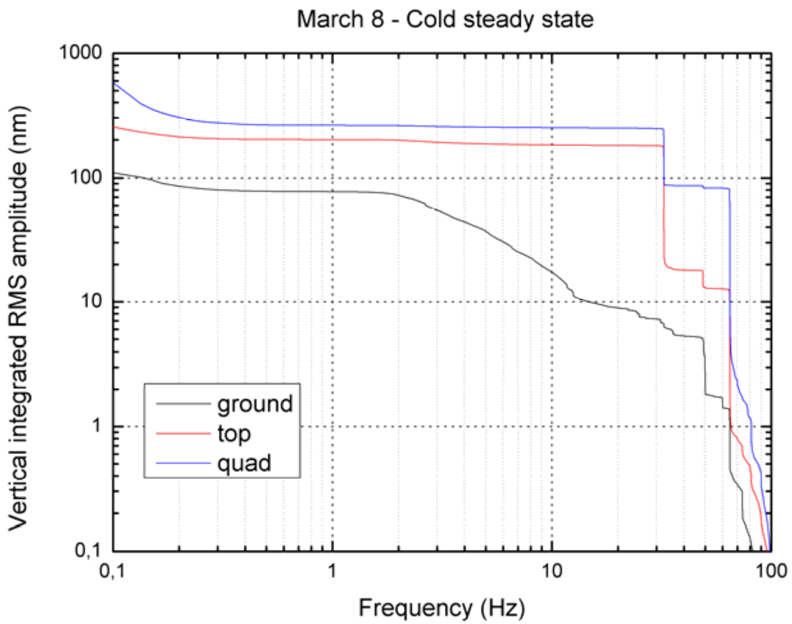
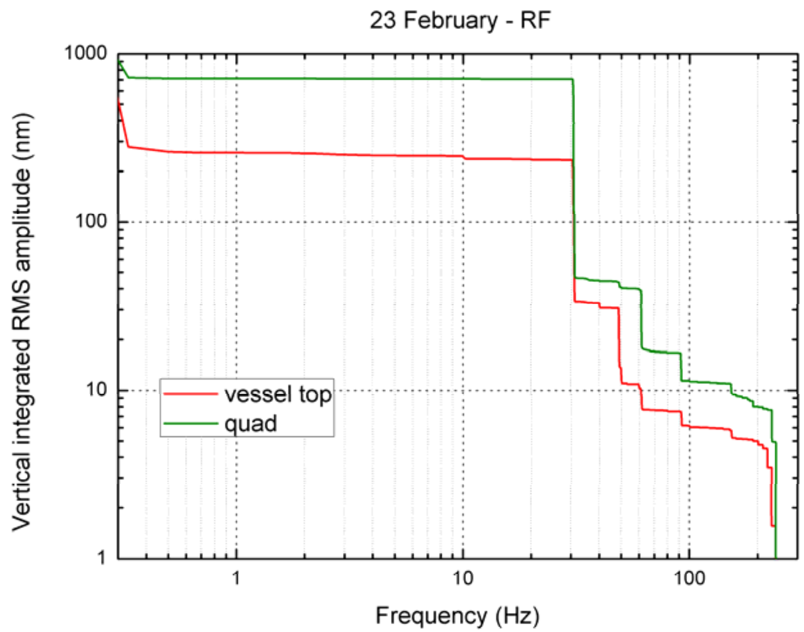


High frequency vibrations stopped completely during the refilling of the cavity reservoir at 9:12AM. The quad-LHe inlet valve is closed in that case.

Same pattern vs time found in the heat exchanger He level. The level follows the opening (%) of the VL2R50 valve. This valve connect the return flow from the quadrupole to the heat exchanger.







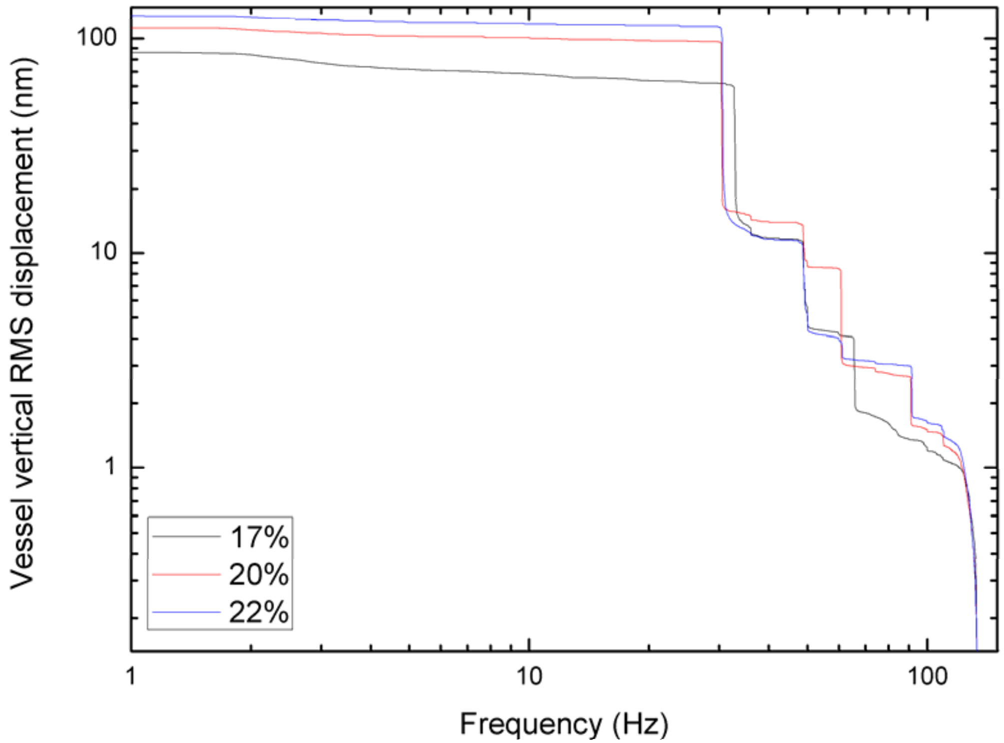
<u>Int.RMS @1 Hz</u>
Vacuum vessel: 200 nm
Quad: 260 nm

<u>Int.RMS @1 Hz</u>
Vacuum vessel: 230 nm
Quad: 730 nm

<u>08 March in steady state</u>
Quad LHe inlet flow: 8.2 g/sec
Quad LHe inlet valve: 20%
Cavity 2K Inlet valve: 56%
Cavity 2K He flow: 5 g/sec
Cavity 2K He level:43%

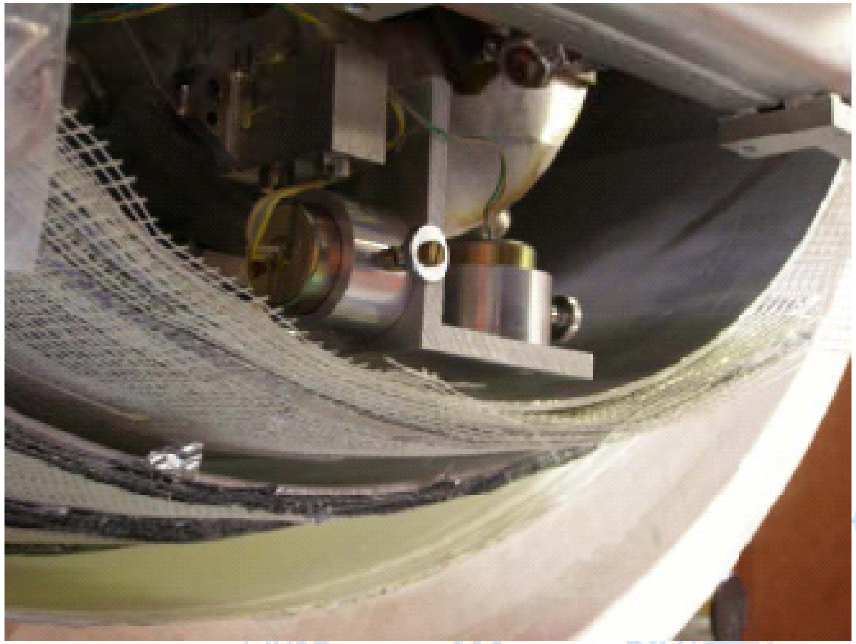
<u>23 February LLRF steady state</u>
Quad LHe inlet flow: 5.5 g/sec
Quad LHe inlet valve: 100%
Cavity 2K Inlet valve: 35%
Cavity 2K He flow: 3.8 g/sec
Cavity 2K He level:43%

Vibration level vs inlet valve opening during 7th thermal cycle (warm measurement)



Module 7 at CMTB:

Two cold geophones+the existing two piezo accelerometers already installed aboard the quadrupole. Complementary geophones on top of the vessel and on the ground. Continuous data acquisition for the whole test (only one thermal cycle). Two or more DOOCS acquisition channels should be available for the beginning of the run. Cool down starting end next week.



Geophone pair mounted in front of the Module 7 quadrupole; new stiffer holder will be installed this afternoon

Module 6 in FLASH linac:

Geophones will stay on Module 6 and Module 7 permanently. MKS asked for more sensors to also equip ACC4 and ACC5. Data acquisition with sufficient number of channels must be produced. Cool down of the FLASH linac is scheduled for the end of July.

Thanks to:

Rolf Lange, Kay Jensch, Wolfgang Maschmann, Peter Smirnov, Oliver Paschold, Helmut Remde

A. Bertolini

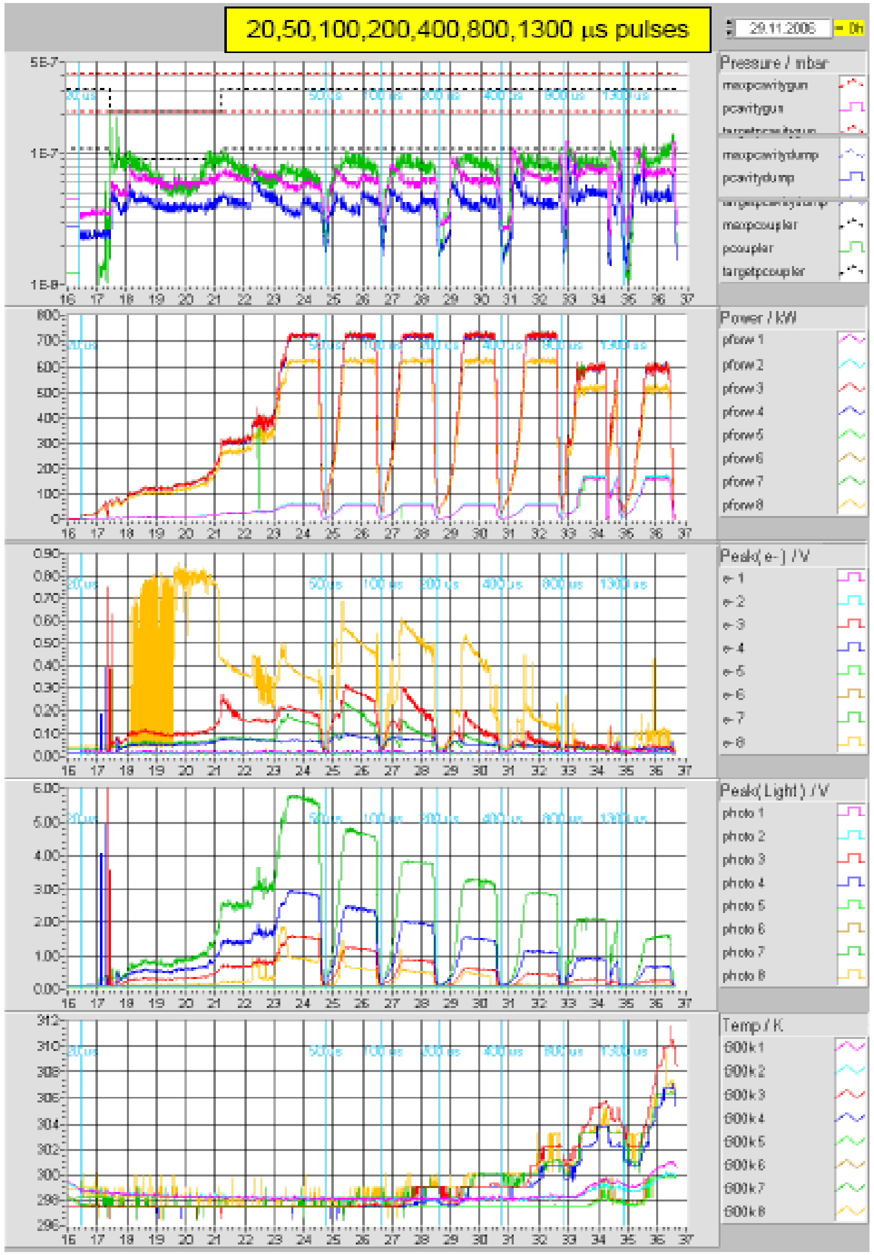
RF Performance

- Couplers
- Cavities

Coupler Processing

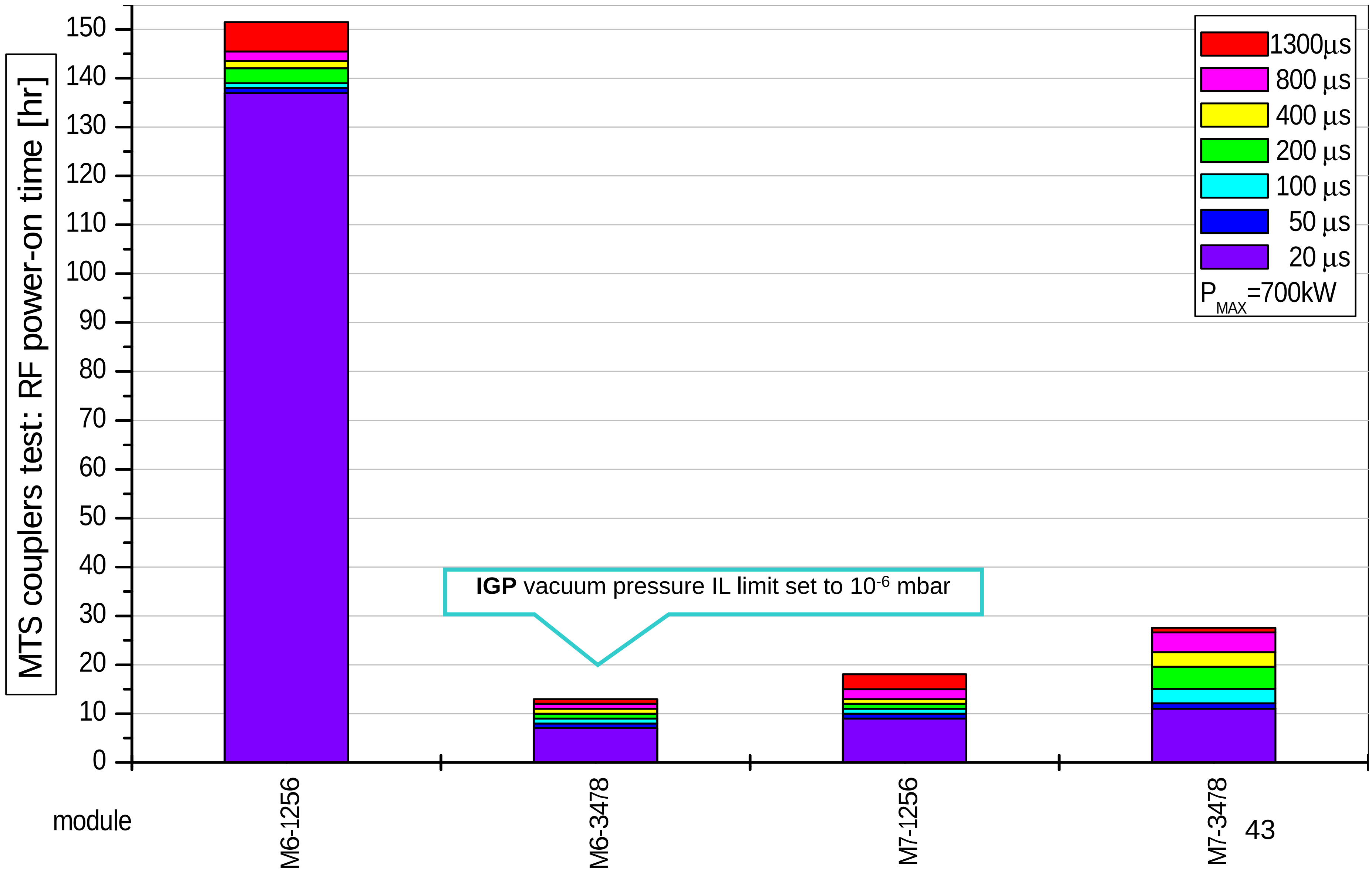
- Done in to steps
  - 1st set of 4 couplers
    - Very tight vacuum interlock thresholts
  - 2nd set of 4 couplers
    - Used ‘relaxed’ vacuum interlock thresholts
- Very fast processing
  - Due to improved handling after pre-processing at LAL Orsay
  - Comparable to individual cavity high power test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

D. Kostin



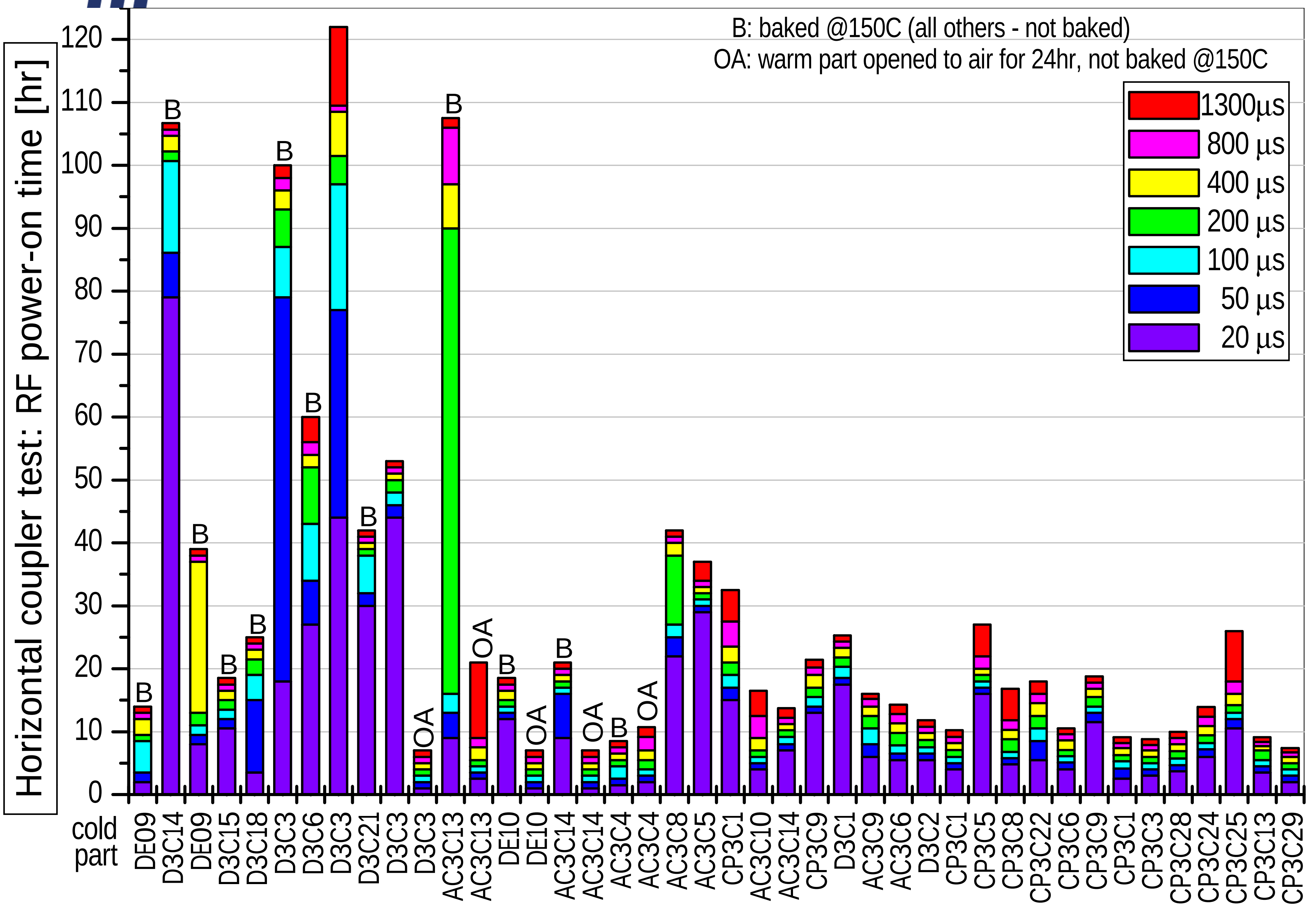
M6 and M7 RF conditioning

D. Kostin



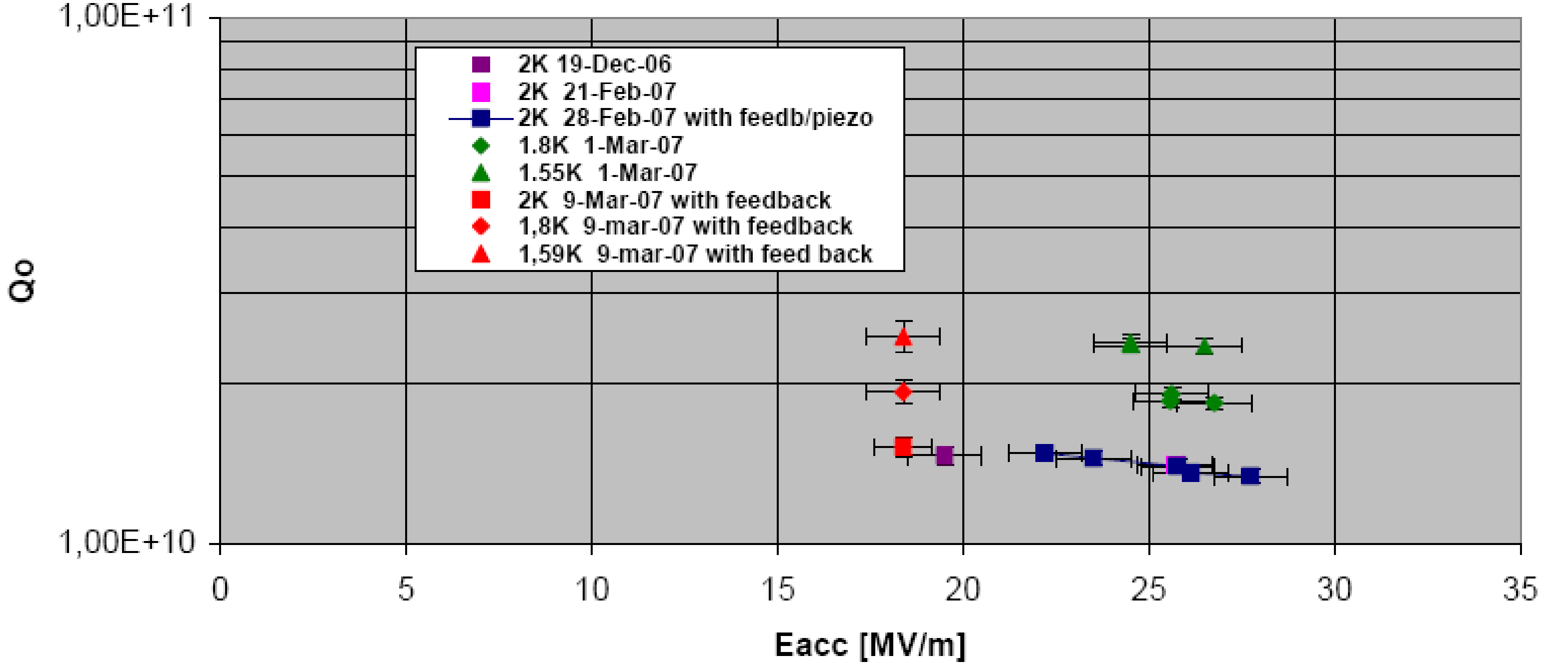
Comparison with Horizontal Test Coupler Processing

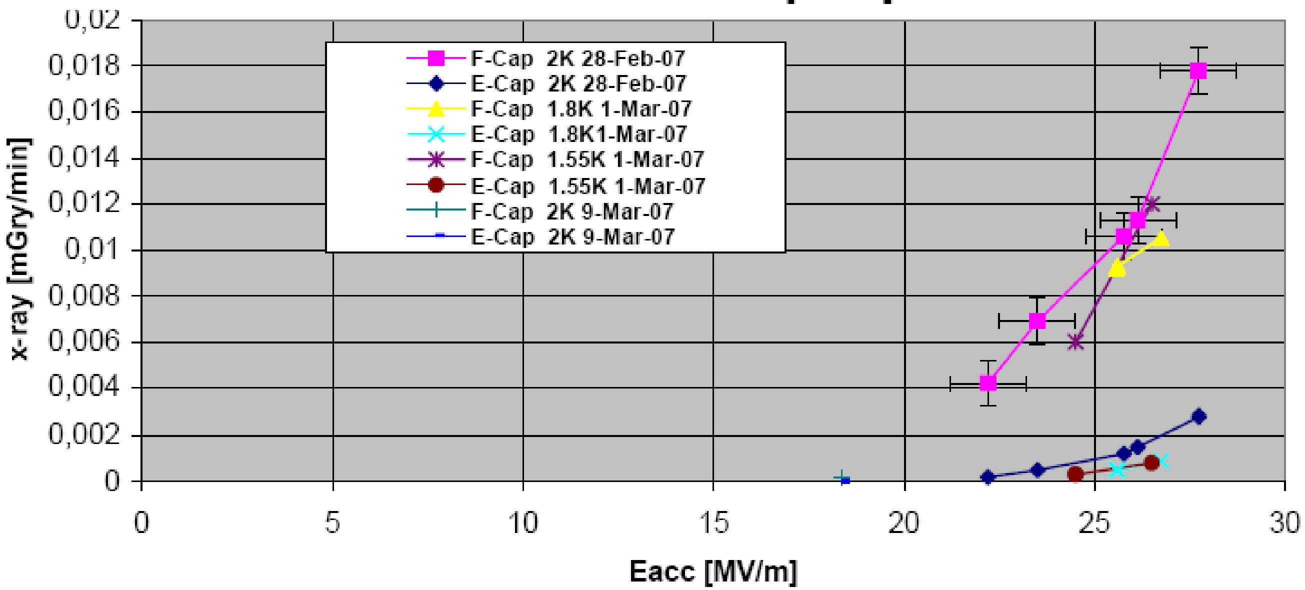
D. Kostin



R. Lange

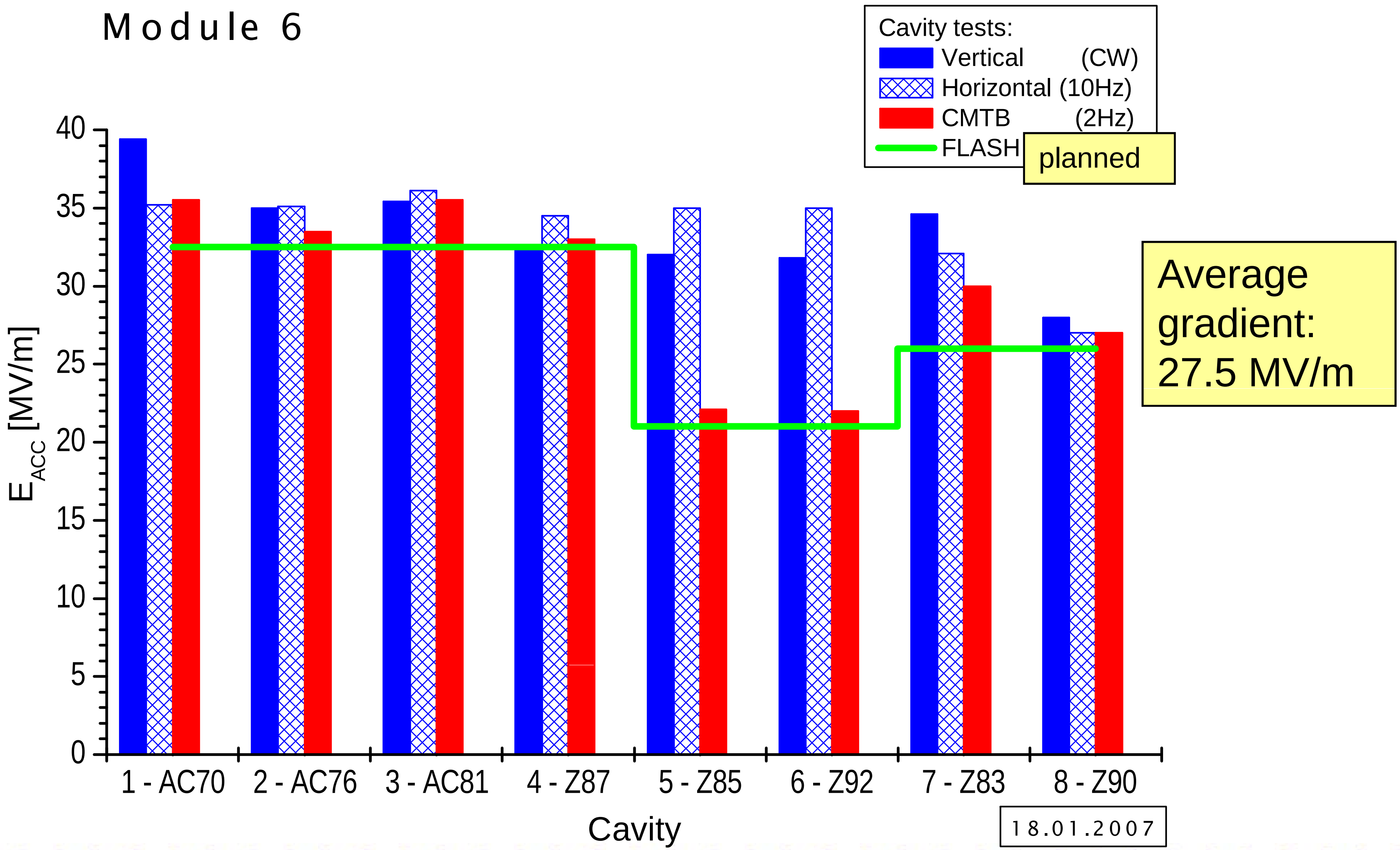
Module 6 CMTB
Meas. Qo/Eacc average gradient 10Hz 500/800us
Status:13-Mar-07 Esch/Kos/Lil/Lan MKS





Cavity Performance

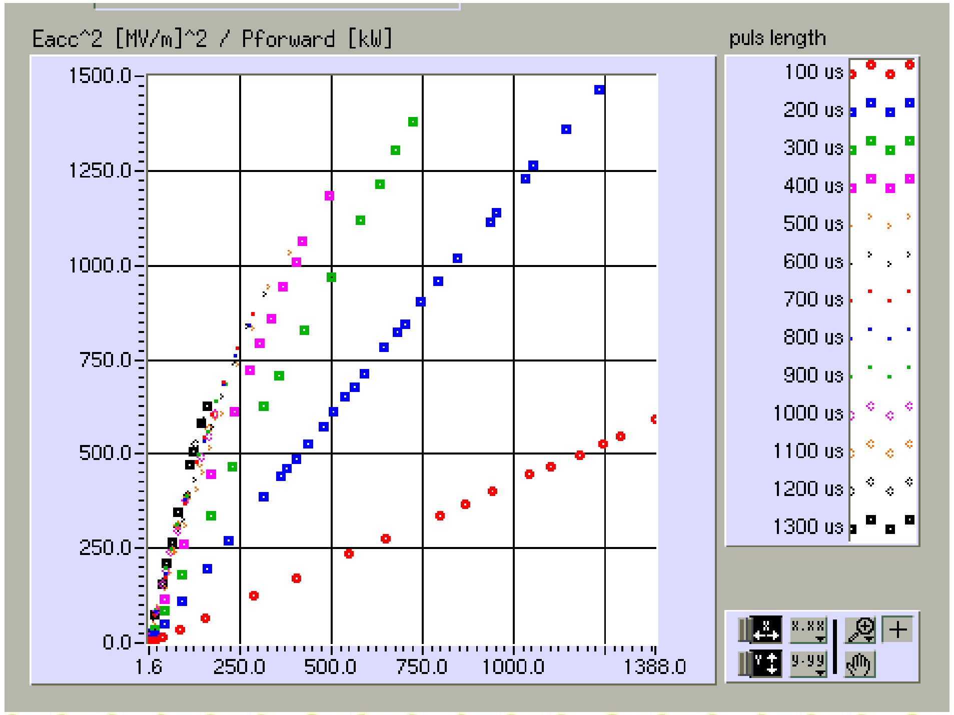
(courtesy D. Kostin – DESY)

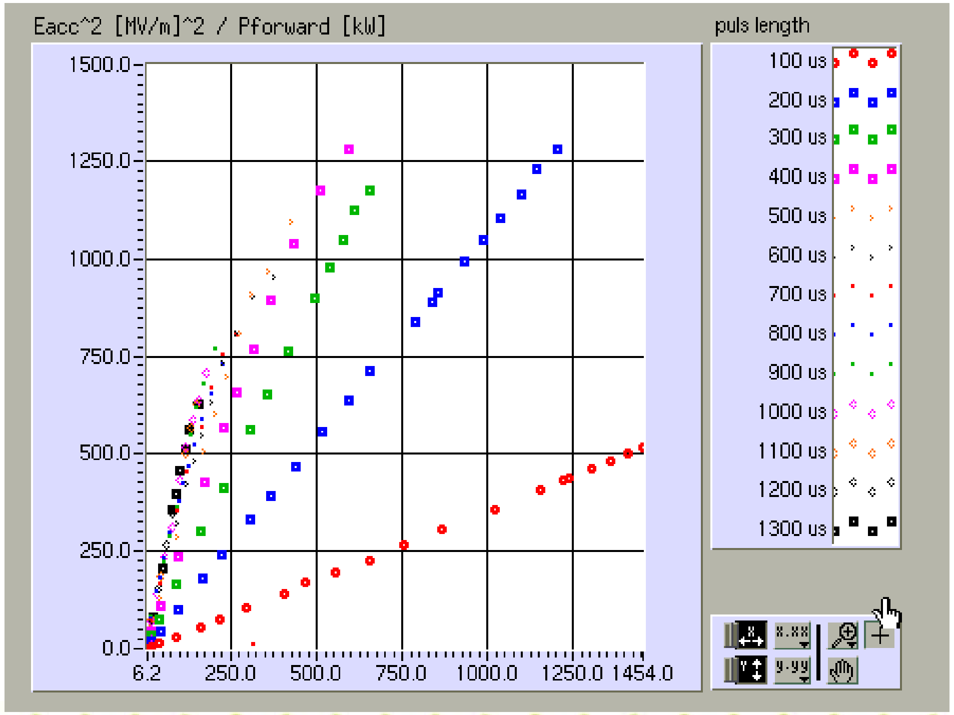


HPP on Cavity 5 +6

D. Kostin

- For short pulses up to 300 us gradient is high >30 MV/m
- Radiation levels are relatively low
- This hints to a thermal quench





Cavity results

- 6 cavities perform very similar to previous tests
  - **Even up to 35 MV/m pulsed operation**
  - **Includes Couplers (see before) and fast tuners (see later)**
- 2 don‘t:
  - **Even after HPP, limitation likely thermal quench**
  - **The reason is not understood**
  - **Suspicious:**
    - Cavities behave like twins in all tests
    - Both cavities have not seen 120°C bakeout for schedule reasons
    - But CHECHIA test was o.k.

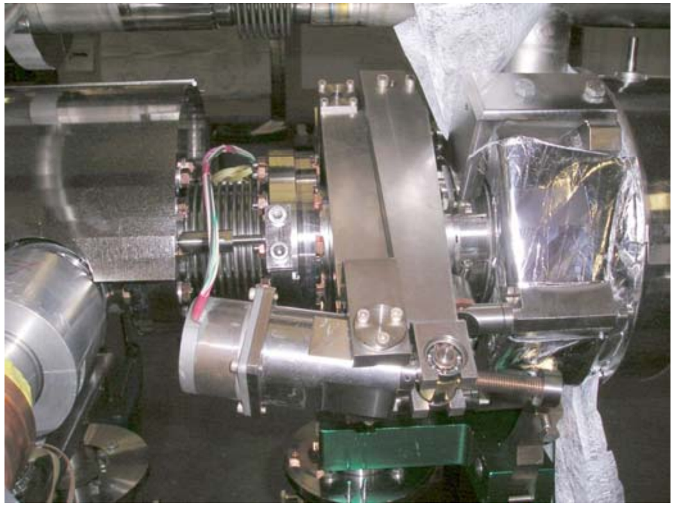
Tuner Tests Overview

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

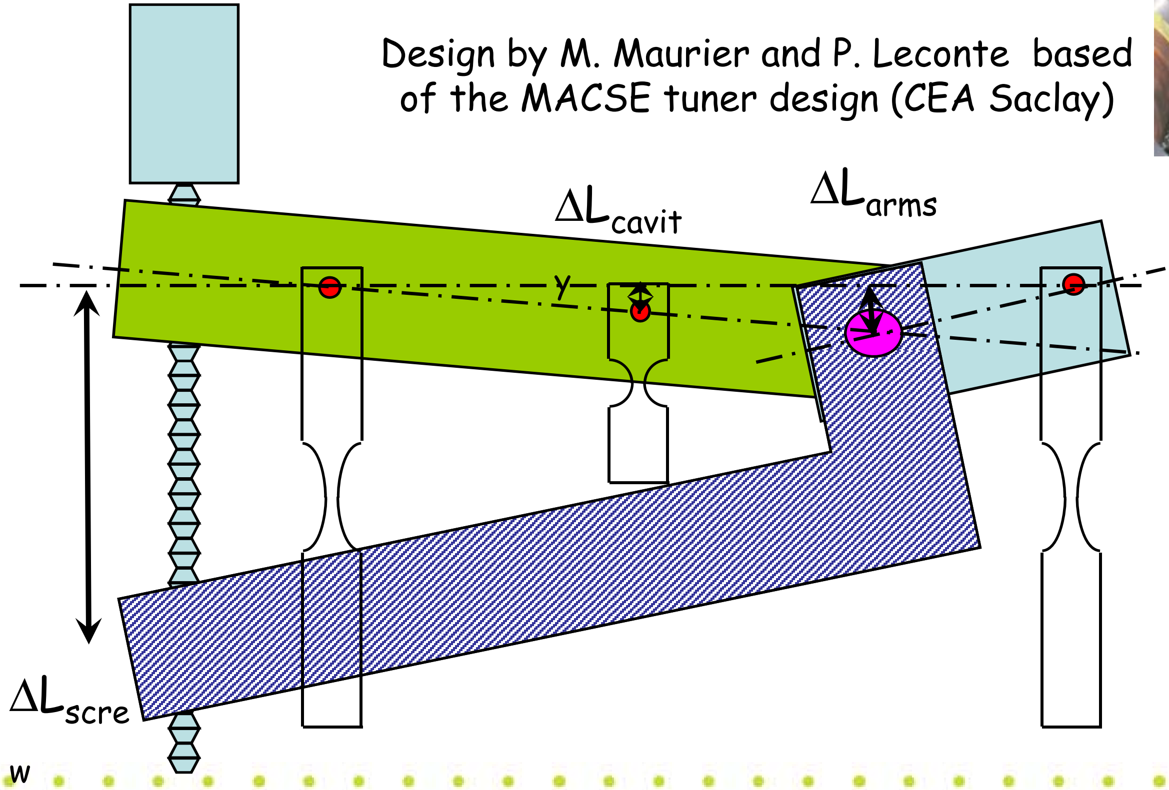
- Two phases
  - **Initial demonstration for each cavity**
    - Measure detuning
    - Compensate detuning individually, one after the other
      - Classical compensation
      - ´Second oscillation´ compensation
      - No RF feedback
    - In addition
      - Work on piezo diagnostics: Impedance 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

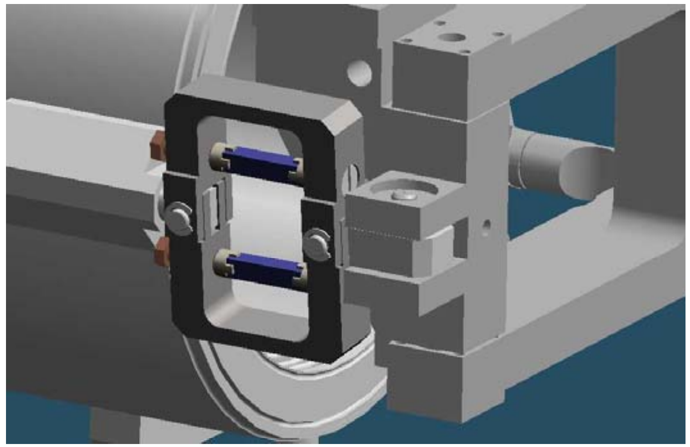
Tuner Setup

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

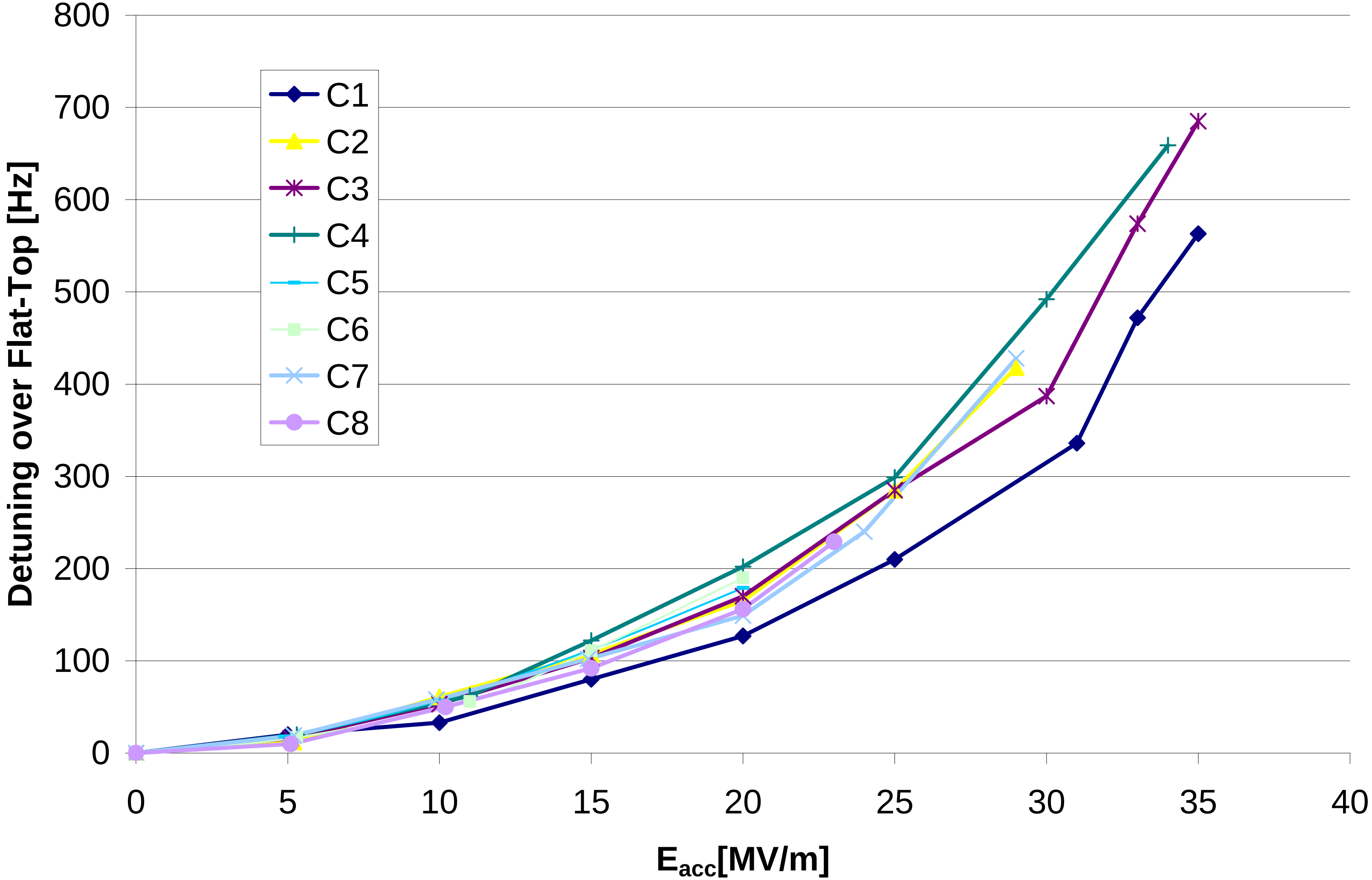


Design by M. Maurier and P. Leconte based of the MACSE tuner design (CEA Saclay)

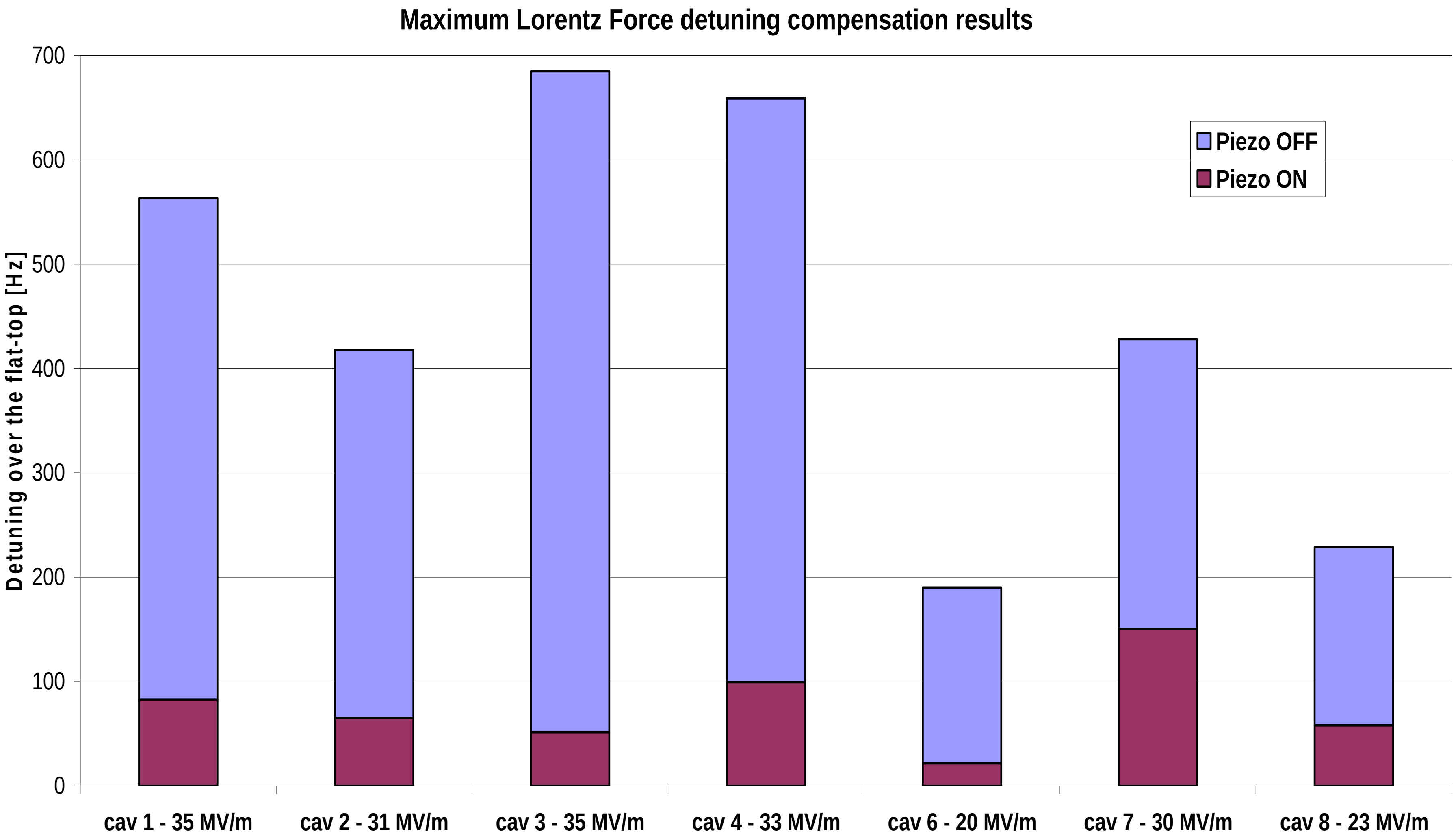




Lorentz Force Detunings in Module 6



Compensated Detuning per Cavity

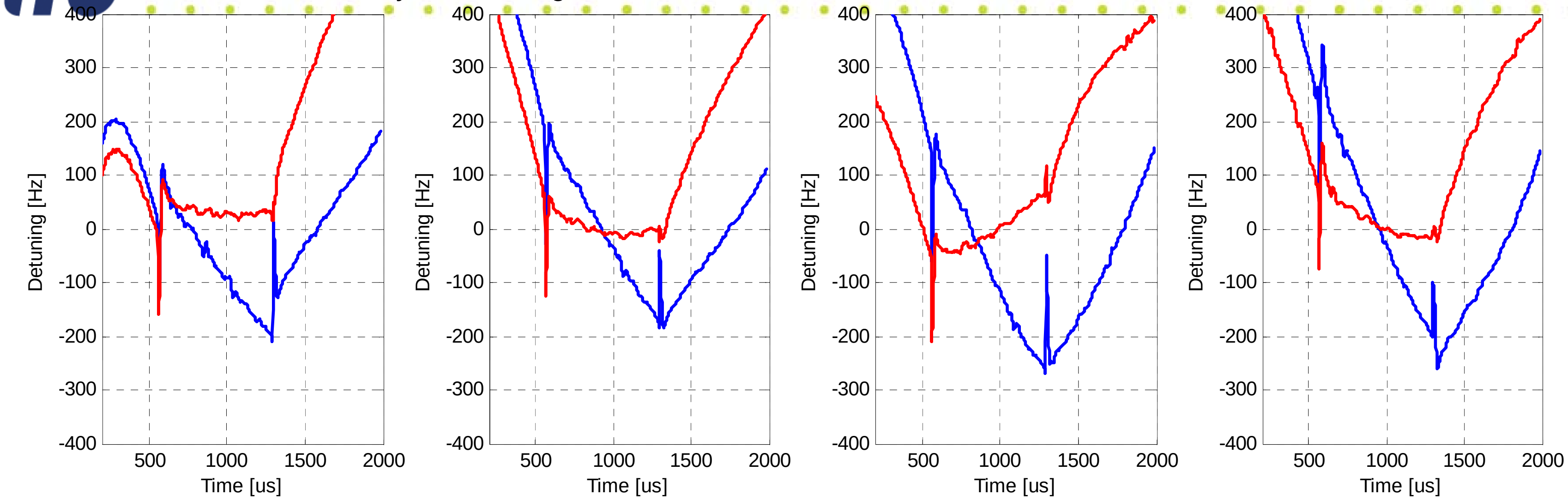


Piezo: Full Module Tests

- Simultaneous operation
  - **Only 2 function generators (FG) available**
  - **Ran 4 cavities on one FG with amplifier and 2 cavities on the other FG with second amplifier**
- RF Feedback on

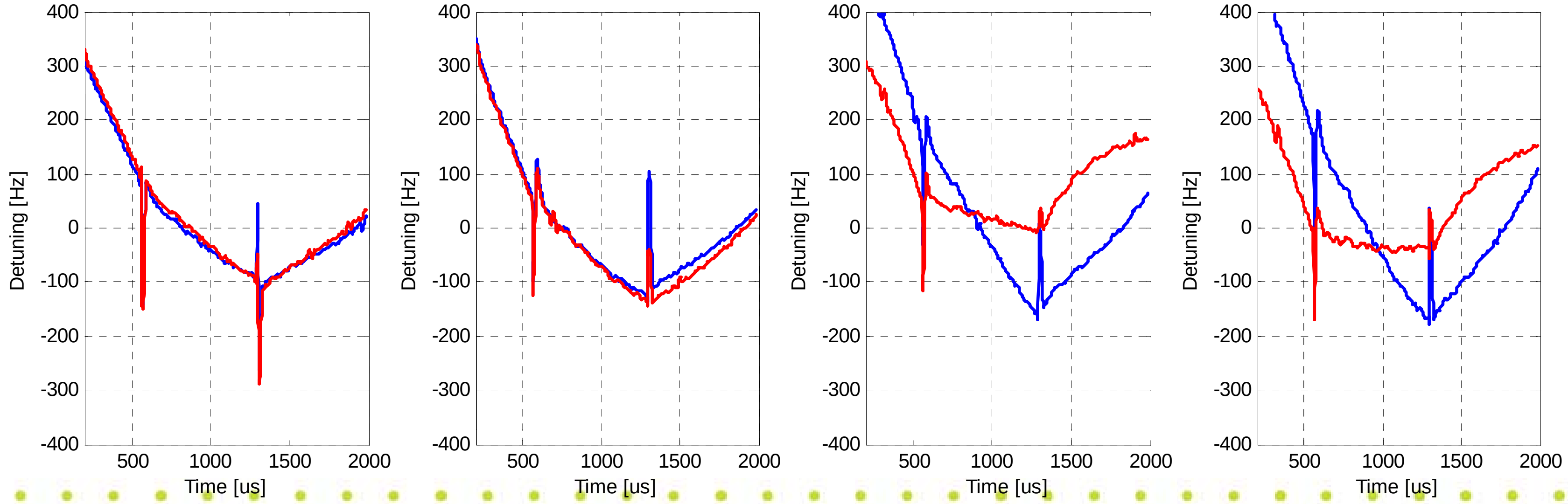
Detuning of all cavities of Module 6 with and without piezo active compensation

Cavity 1,2,3,4 : signal 1 - half sin 2.5 ms width, 60 V, 640 us advance

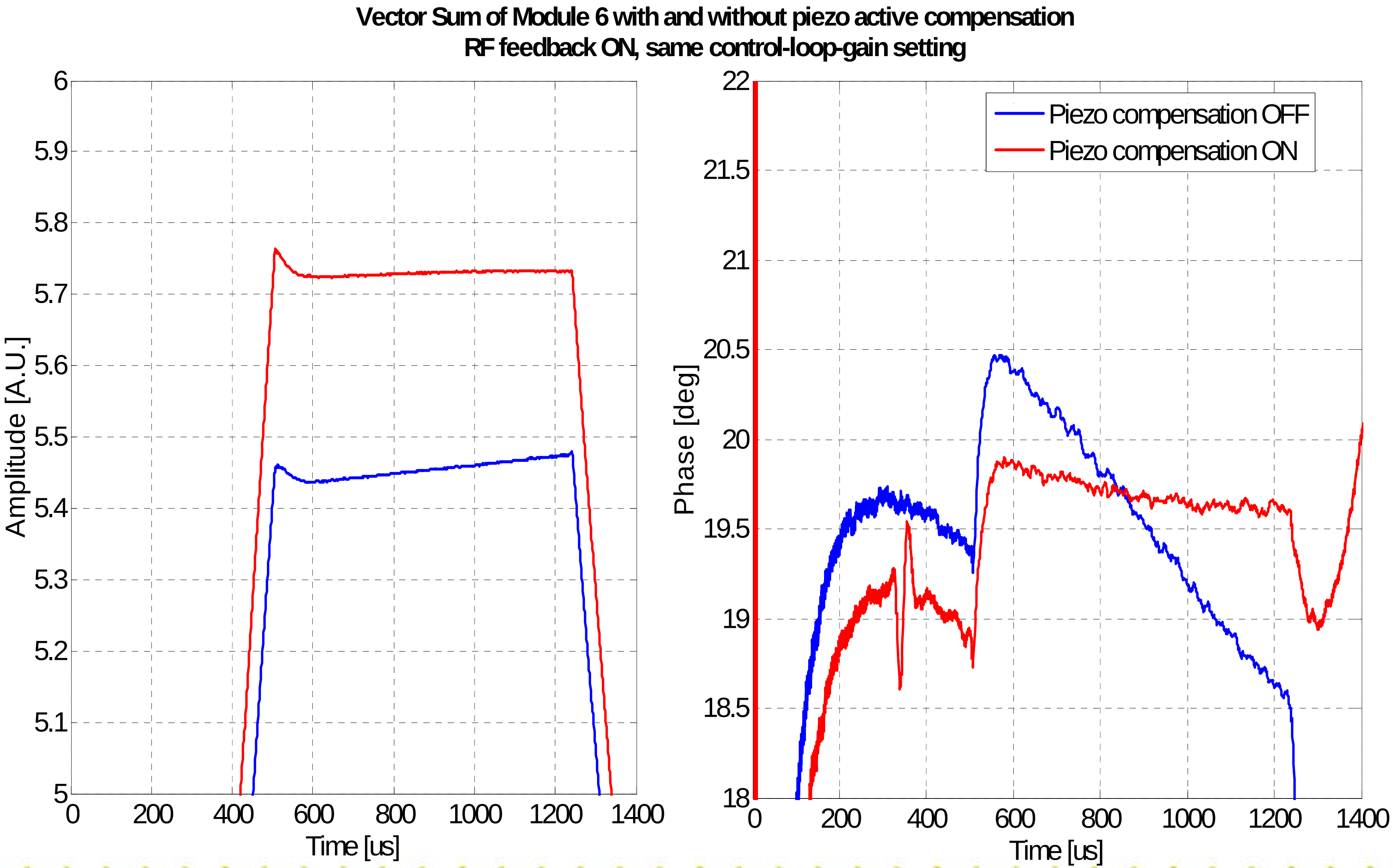


Cavity 5,6 : no signal - no active compensation

Cavity 7,8 : signal 2 - half sin 2.5 ms width, 64 V, 640 us advance

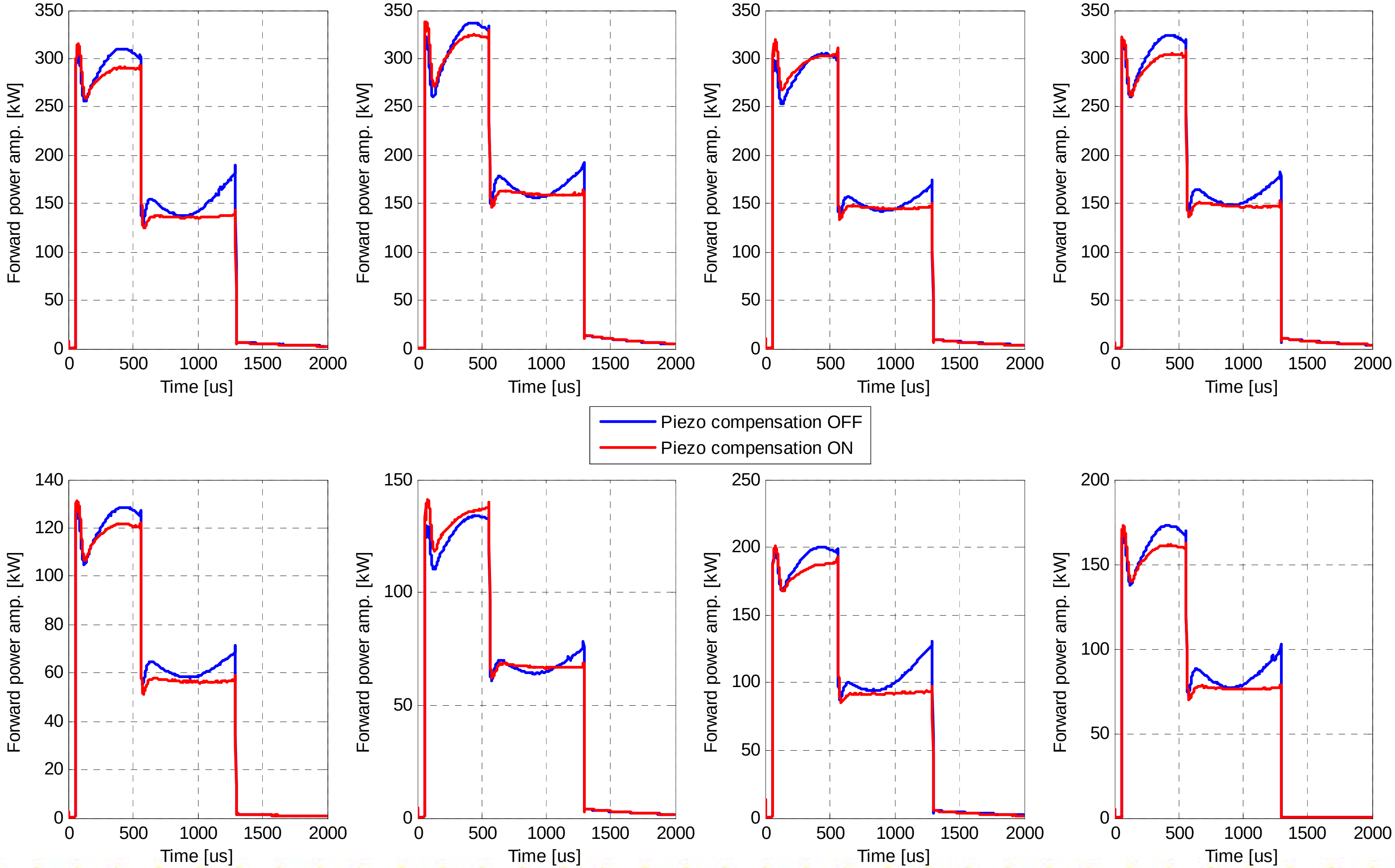


Operation of Full module – Vector-Sum



Operation of Full Module – Forward Power

RF feedback switched ON on module 6 in CMTB. Collection of all amplitude of forward power signals with and without piezo active compensation



Conclusion on M6 Test

- CMTB has proven to be essential tool for thorough linac-independent tests of modules
- M6 has passed several important tests
  - **Coupler processing smooth and short**
  - **Alignment over several thermal cycles was repeatable**
  - **No leaks**
  - **Piezo compensation**
  - **Vibration in warm o.k.**
- Nonetheless some issues remain
  - **Cavity performance degradation**
  - **Vibration in cold state need more still more understanding**
    - Nonetheless a suspect for the ~30 Hz peak has been found
- Minor evolutions in design will be tested on M8
  - **Important step toward a XFEL prototype test**

Next Tests on S1

- Planned until 2009
  - **DESY**
    - M7
      - Probably not 'Proof-of-Existence'
    - M9
      - probably no slow-down due to cherry-picking
    - M10
      - Could pool cavities cavities from regions to assemble a cryomodule
      - e.g. x cavities from another region in exchange for XFEL cavities later
      - support from task force
  - **US**
    - 2007
      - Kit = M8
        - » First assembly experience at FNAL
    - 2008
      - 1st US built
      - 2nd US built
        - » T4CM
        - » this could/would be delayed for cherry-picking
    - 2009
      - 2 more T4CM
  - **Japan**
    - STF Phase 1
- Evaluate model on cavity production
  - **consistent with yielding enough cavities by end 2008?**
- Strategy
  - **to focus on a fast-track module with cavities from several regions**

S0S1 Planning: Estimation of Resources

- Estimate impact on whole project
  - What is the penalty for taking a cavity performance distribution of today?
- Estimate R&D cost (material and manpower)
  - cavity production is an expensive R&D item
  - include processing
  - Need continuous flow of smaller production batches as this allows to continuously improve processes and QC
    - will be used for estimation of final batch size
  - Develop 3 scenarios
    - Optimistic case
    - Realistic case
    - Pessimistic case
- Timeline for the S0S1 plan

Ultimate S0 Production experiment

- For the ultimate experiment
  - **only qualified vendors**
  - **only qualified preparation infrastructure**
  - **will start end 2009**
    - would be post-EDR
  - **Number of cavities should be A x 30 where A is greater or equal to 1**
  - **could take into account further results from parallel R&D effort (single-cell and tight-loop)**

ILC Cost for lower average gradients (following C. Adolphsen)

- Assume a distribution of gradients of a current cavity production with a large spread
  - **average 28 MV/m ranging from 22-34 MV/m, flat distribution**
    - e.g. DESY 4th production
  - **tweak power distribution**
  - **reduce overhead a bit**
    - due to a small loss in the efficiency of the RF unit
  - **increases linac length by 12.5 %**
  - **yields 7% increase of total project cost ~500 MILCU**
- Thus a major cost risk is associated with the average gradient.
  - **As long as a wide range of gradients can be accommodated only the average gradient matters.**

What precision on the width of the distribution is needed?

- Calculate the precision on ‚faulty' cavities
  - **N= number of cavities in a production-like effort**
    - cavities
      - from one manufacturer
      - processes once or twice
  - **take delta e = sqrt(e*(1-e)/N)**
  - **calculate cost increase for the project**
    - if N=100, e=20% then delta e = 4 %
    - thus worst case need 4% more cavities
      - 30 MILCU
    - if N=60, e=20% then delta e= 5.1 %
      - 38 MILCU
    - if N=30, e=20% then delta e= 7,3 %
      - 54 MILCU
- This should be probed by a final batch of N cavities
  - **Time-line**
    - post-EDR
  - **N is a cost issues**
- Nonetheless one can already learn a lot looking at three scenarios for cavity productions
  - **takes into existing plans in the regions**
  - **includes pessimistic, realistic, optimistic planning (due to available resources)**

Scenarios Cavity Production

- Pessimistic case
  - **EU**
    - ‚only‘ XFEL
      - limit processing to XFEL gradient (~28 MV/m)
  - **Japan flat budget**
  - **US flat budget**
- Realistic scenario
  - **EU**
    - XFEL
      - limit processing
    - 30 cavities from FP7
      - ILC processing
  - **Japan**
    - Flat
  - **US**
    - Minor increase in cavity numbers
- Optimistic scenario
  - **EU**
    - XFEL
    - 30 cavities from FP7
    - Additional high-gradient programme at DESY
  - **Japan**
    - flat (+20%)
  - **US**
    - roughly double number of cavities in 2009: 48

Cost for these Scenarios

- calculate the cost fabrication and one process cycle
- assumes the existence of cavity preparation infrastructure
  - **infrastructure development is not considered as part of S0 production**
  - **nonetheless it is closely related to the tight-loop**
  - **need to include number of preparation cycles (second preparation) for full cost estimate**
- need to add process cost for tight-loop
  - **30000 k$ per process includes labor**
  - **81 processes in first loop**
  - **27+ processes in second loop**
  - **roughly 3.5 M$**
- need to add the final batch for S0 production
  - **30 cavities**
  - **roughly 3 M$**
- $ on this slide / need to compare to ILCUs eventually

		KEK				US			EU						
		2007	2008	2009	2006	2007	2008	2009	2007	2008	2009	Sum over 2007-2009	Cost Fabrication	Cost Processing	Cost Sum
	pessimistic	8		24	8	8	12	20	30	20	30	160	12000000	5600000	$ 17 600 000.00
	realistic	8		24	8	20	20	30	30	30	60	230	17250000	8050000	$ 25 300 000.00
S0	**optimistic**	10		24	8	22	24	60	30	30	60	268	20100000	9380000	$ 29 480 000.00

Value added from these scenarios

- Get an estimate
  - **on average gradient**
    - see 4th DESY production
  - **on spread of the gradient**
    - see 4th production again
- Even the pessimistic scenario will improve this to
  - **an average gradient and a gradient spread**
    - which is based on many more cavities
    - additional capacity for cavity fabrication (new vendors) and preparation (added infrastructure at labs)
    - A data set with improved final surface preparation will be available
- thus this information will be submitted with a recommendation for the final gradient of the ILC

Evaluation of the pessimistic scenario

- Roughly 160 cavities total up to 2009 (include 2006 cavities)
  - **about 80 will be put through a mature infrastructure for the final preparation step (EU)**
    - tighter quality control at the vendors
    - this might differ from the final ILC preparation process
    - will be (partially) used for final treatment setup at companies
  - **the other 80 will be partially from qualified vendors and new vendors**
    - use new infrastructure tailored to the final ILC preparation process
- The fabrication yield can be estimated from this data set at least to exclude major fabrication problems
- This scenario will provide a lower boundary of the average gradient
  - **minimum expectation is a gradient level of the 4th production at DESY ~27 MV/m with a spread of 4 MV/m**
    - Will include company treated cavities
  - **with an optimized process available in the other regions an improvement of the average gradient should be demonstrated**

Evaluation from the other scenarios

- More cavities are put through the optimised ILC process assumed to be available by mid 2008
  - **Have to assume new vendors**
  - **Pessimistic scenario: 80 cavities**
  - **Additional in 2008/09**
    - the numbers of cavities which could be subjected to a new process increases to 160 (188) cavities in the realistic (optimistic) scenarios
    - Some of these will be tested only in 2010
  - **This is the demonstration of a higher average gradient with better statistics**
    - due to improved preparation steps
    - results available for the EDR

S0 Plan Cost Estimation

- Optimistic with final batch + tight-loop
  - **36 M$**

- This needs to be correlated to
  - **Reduction of the average gradient for the ILC**
    - ~ 500 MILCU
  - **compare to the risk of the width**
    - this is roughly half of what be the final cost impact on the project

XFEL is an Important Asset

- Material issues
  - **scanning for a large batch of material**
  - **qualifying more vendors**
- continuous production of cavities in line of preparation improvements
  - **is a significant part of the cavity data set**
- pre-series will start 2008
  - **EP is becoming industry process from autumn**
- Design for manufacturing for the cavities
  - **weldings**
- Quality assurance
  - **defining a reasonable and affordable QC procedure**
- (Coupler industrialisation)

- Module design has been reviewed by industry
  - **Report is due soon**

XFEL: E.g. More Niobium Vendors

- Plot to be added

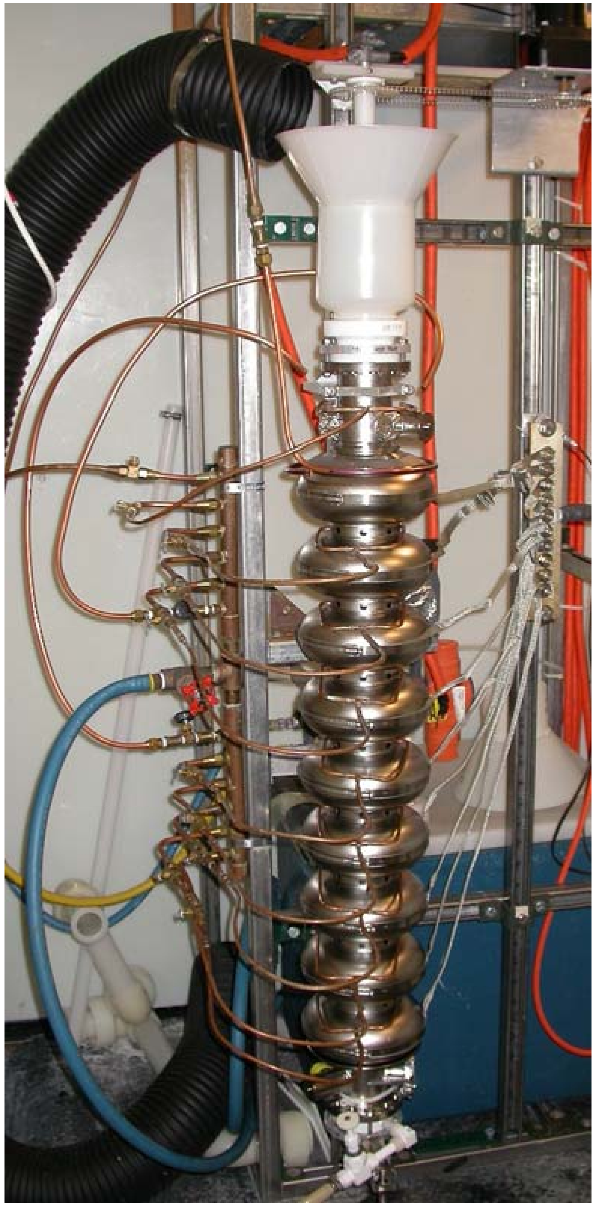
Alternatives

– […. Still to be edited …]

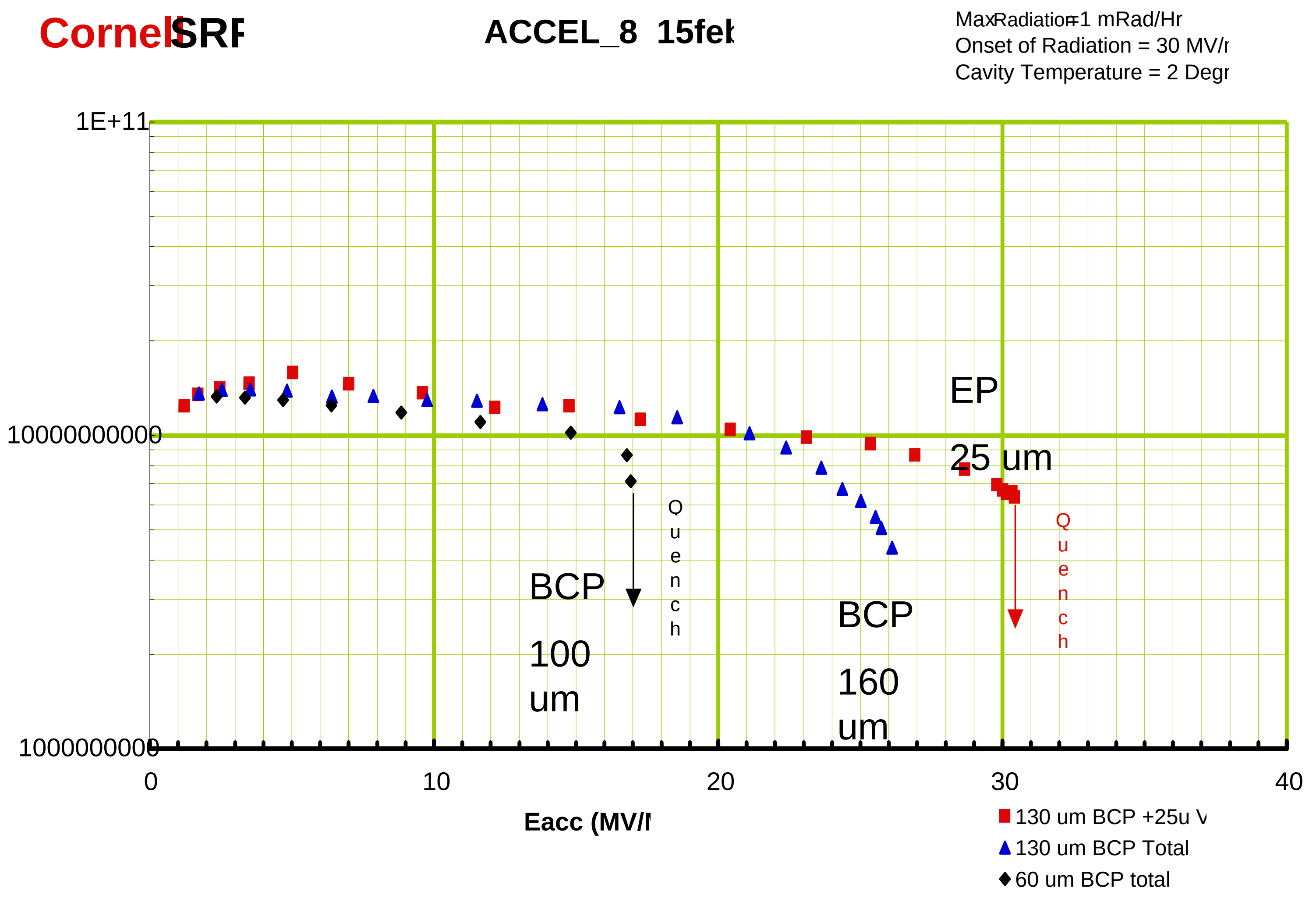
– LL, Re-entrant
– Vertical EP
– Large-grain with and without EP

Vertical Electropolishing Set-up

- 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



Vertical EP Moves Forward ACCEL- 8 Test Results



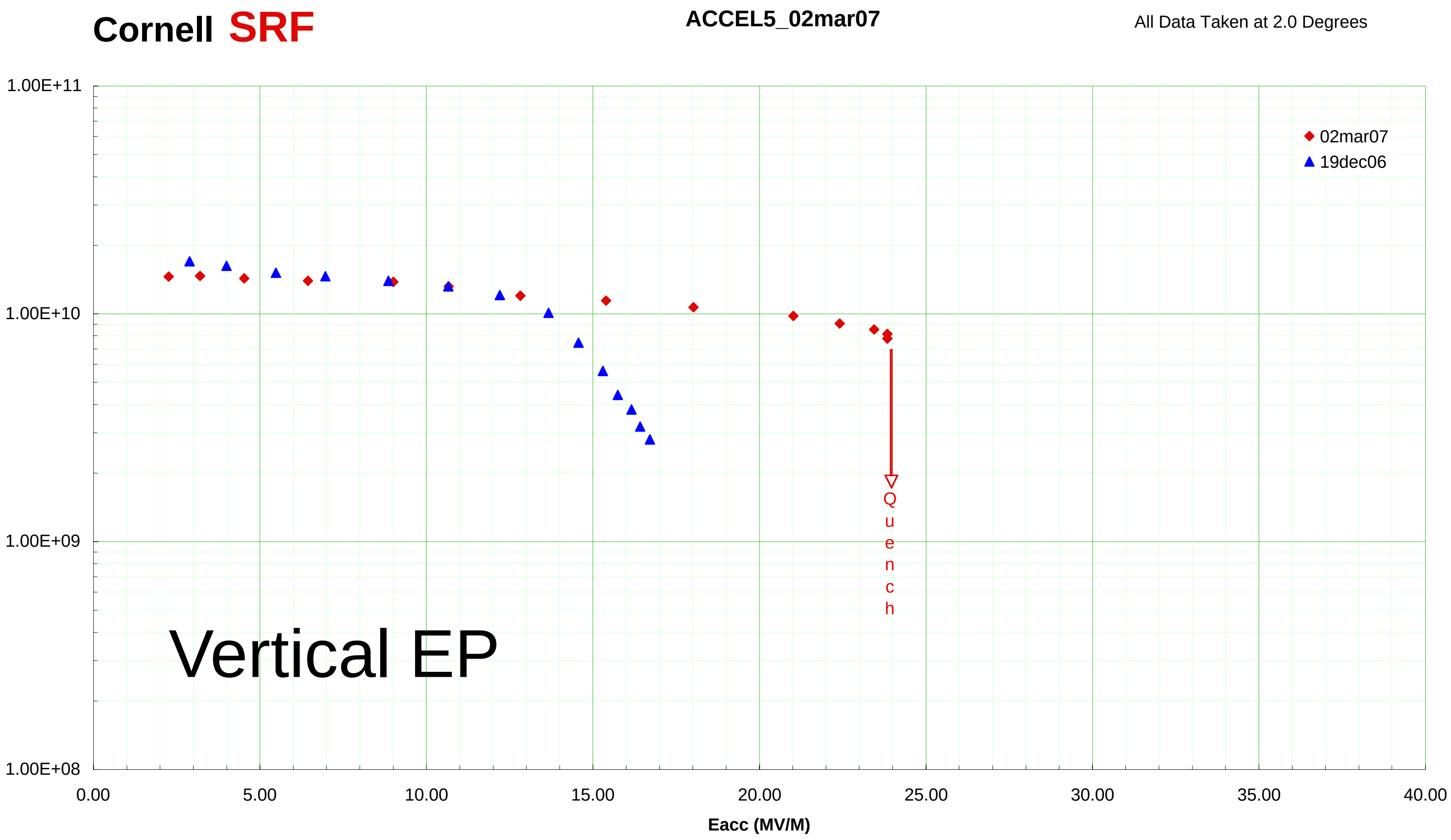
ACCEL 8 Treatment Details

- BCP 110 μm (+ 50 μm on parts at ACCEL) + HPR
- <u>No Heat treatment at 800 Deg C</u>
- Eacc = 26 MV/m (Limit : high field Q-slope)
- Vertical EP, 25 microns, bake 110 C, 48 hours
- Eacc = 30 MV/m
  - No field emission
  - Limit: quench
- Vertical EP: 70 microns
  - Sent to Jlab for H outgassing

ACCEL- 5 Treatments

- Vertical EP : 120 micron
- 600 C, 12 hour bake at Jlab to remove H
- Flash BCP (< 10 microns) + HPR & test
- Eacc = 17 MV/m (max)
  - No field emission
- Need more material removal after furnace bake
- Vertical EP, 25 microns
- Eacc = 24 MV/m, Flat Q vs E, Quench
- Remove another 105 microns, sent to Fermilab for H outgassing

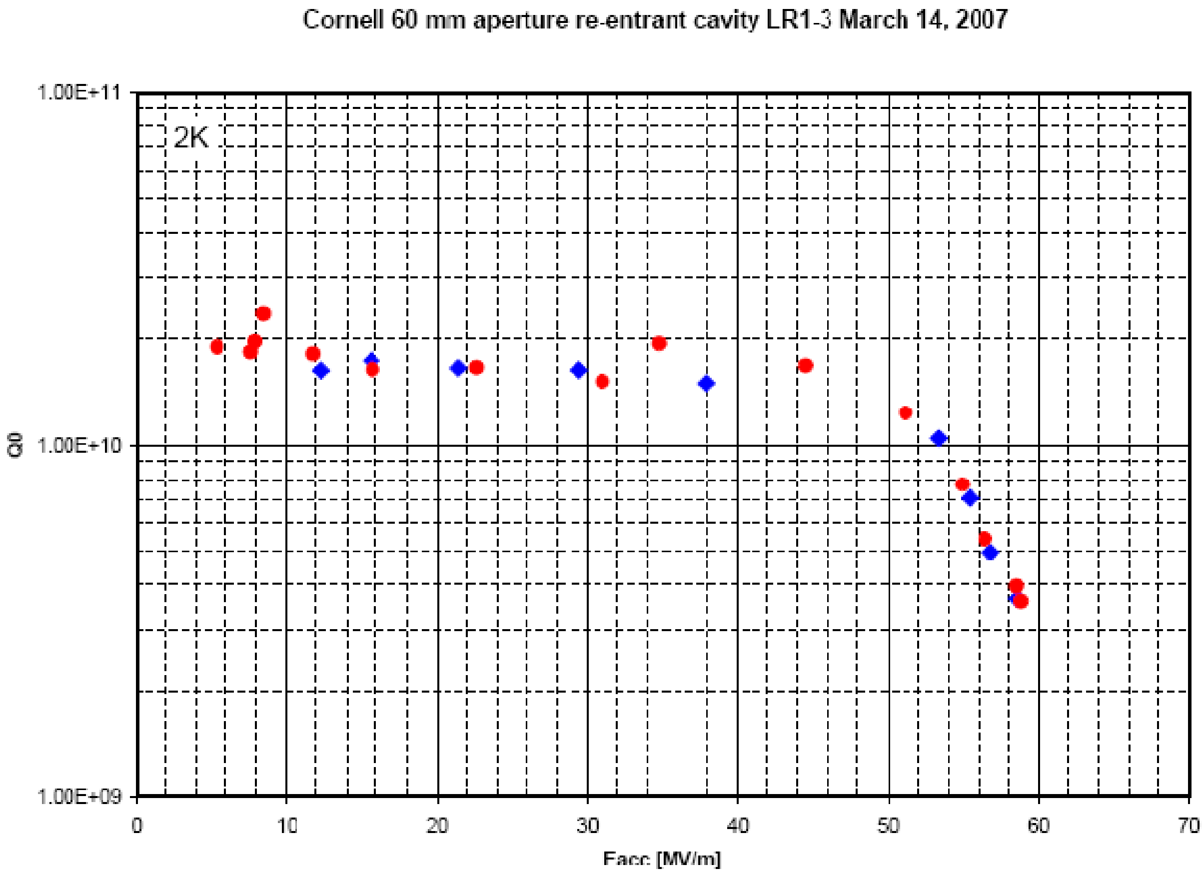
Vertical EP - ACCEL-5



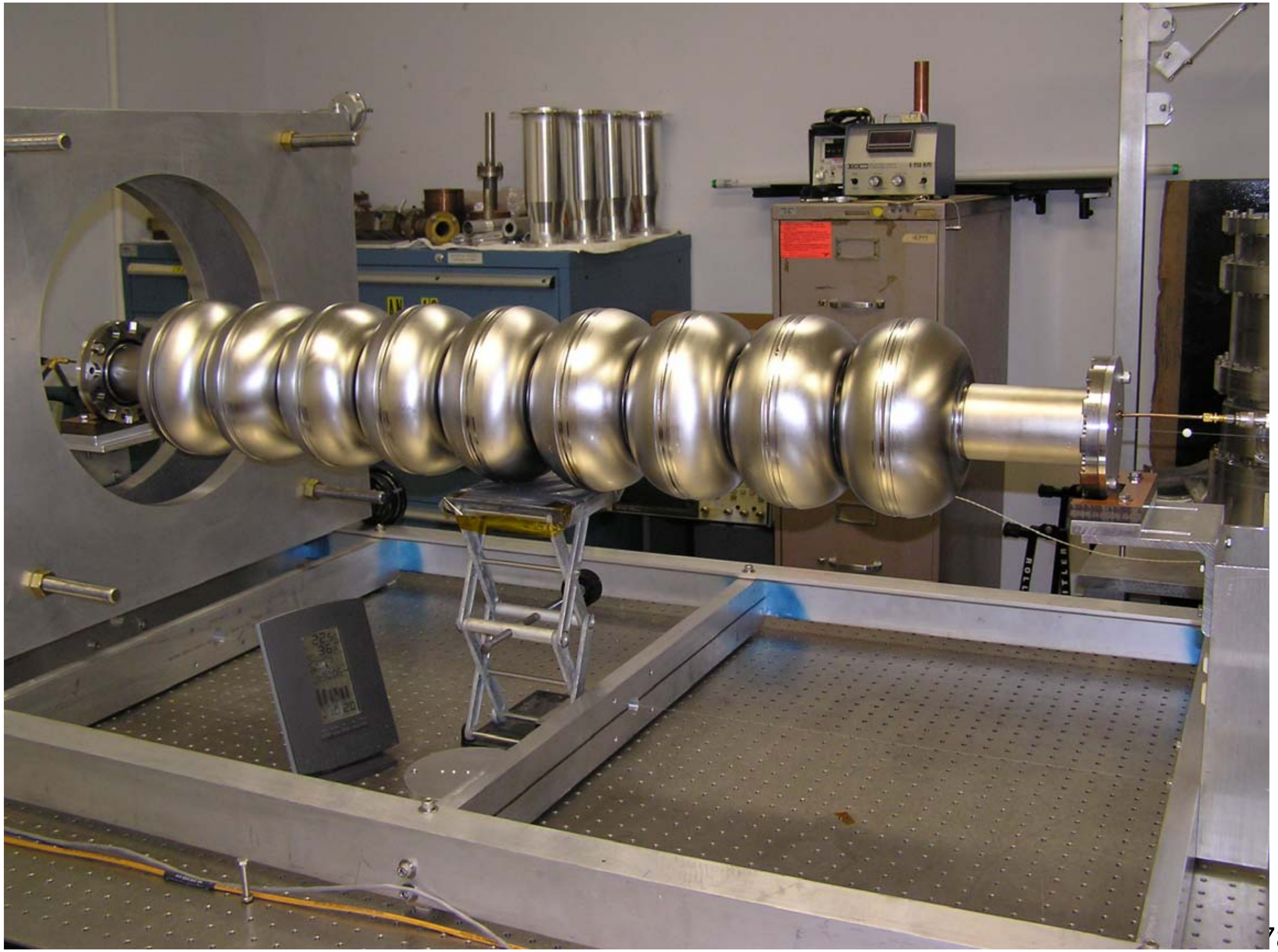
60mm-Aperture Re-Entrant Cavity

Best Eacc = 59 MV/m

RE-LR1-3



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



S0S1: Major Milestones until 2009

- Ongoing cavity exchange
  - **first cavities have been identified**
    - KEK-US and vice-versa
      - cavities will go to DESY
    - DESY-KEK
      - at least one direction
    - results are partially available by end of this year (2007)
      - a third of those tests by end of the year
    - first loop finished by mid 2008
    - second loop by beginning 2009
  - **Production-like**
    - will have tested ACCEL cavities in the US
      - will have tested the AES cavities
    - 8 (10) cavities at Japan
    - will have tested 15 ACCEL TESLA-short
    - will have tested the 6th production at DESY
  - **S1**
    - tests of M7, M8 (FNAL), M9, STF Phase1
    - M10 as a dream module?
    - Acquisition of further modules
      - 2 in 2008 (1st US, 1st T4CM)
      - 2 in 2009 (2nd T4CM, T4CM9)

Bottom Line

- S0 Plan has started
  - **Tight-loop started**
    - hot candidates
      - Fresh acid
      - Ultrasound degrease
        - » Multi-cells at JLab
    - Common data sets are being developped
    - Dedicated manpower added to task force
- Production-like
  - **Resource-intensive**
  - **several batches is underway**
  - **a plan becomes more realistic**
    - scenarios have been developed
- Facilities are becoming online
  - **Jlab**
  - **others as well**
- Alternatives
  - **Single-cells**
  - **Vertical EP**
  - **Large-grain material**

Bottom line II

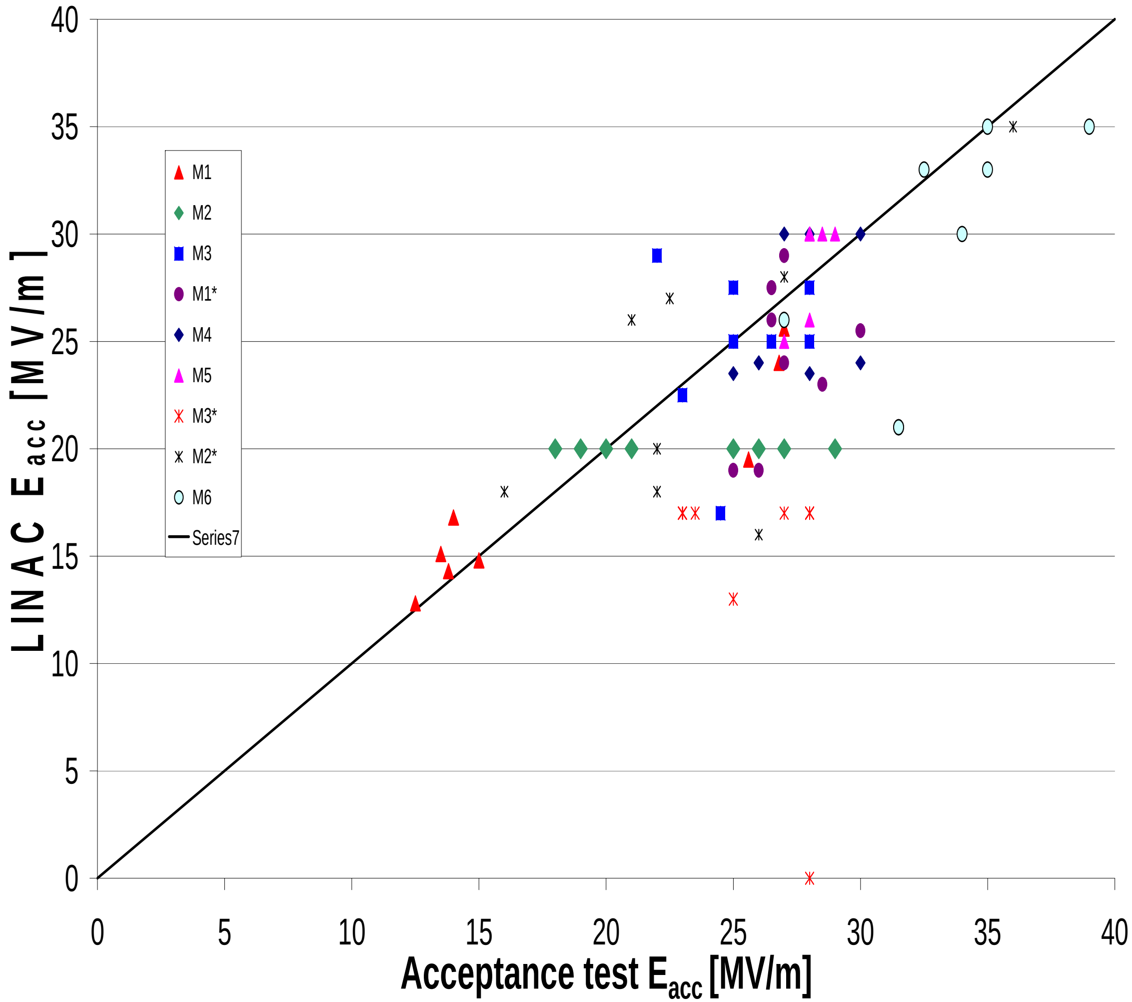
- S1
  - **M6 important**
  - **Needs more work**
  - **Resource-intensive**
  - **Long lead times**
    - propose to build proof-of-principle across regions
  - **Interface to S2**
- Plan
  - **becomes much clearer as resources are known better**
  - **Worst case**
    - Even then a lot of data available for an educated decision for the EDR
  - **Best case**
    - Still final full production-like assessment will be later than the EDR
- XFEL
  - **several points of connection have been discussed and are critical to the success of the ILC R&D program**

- The end ……

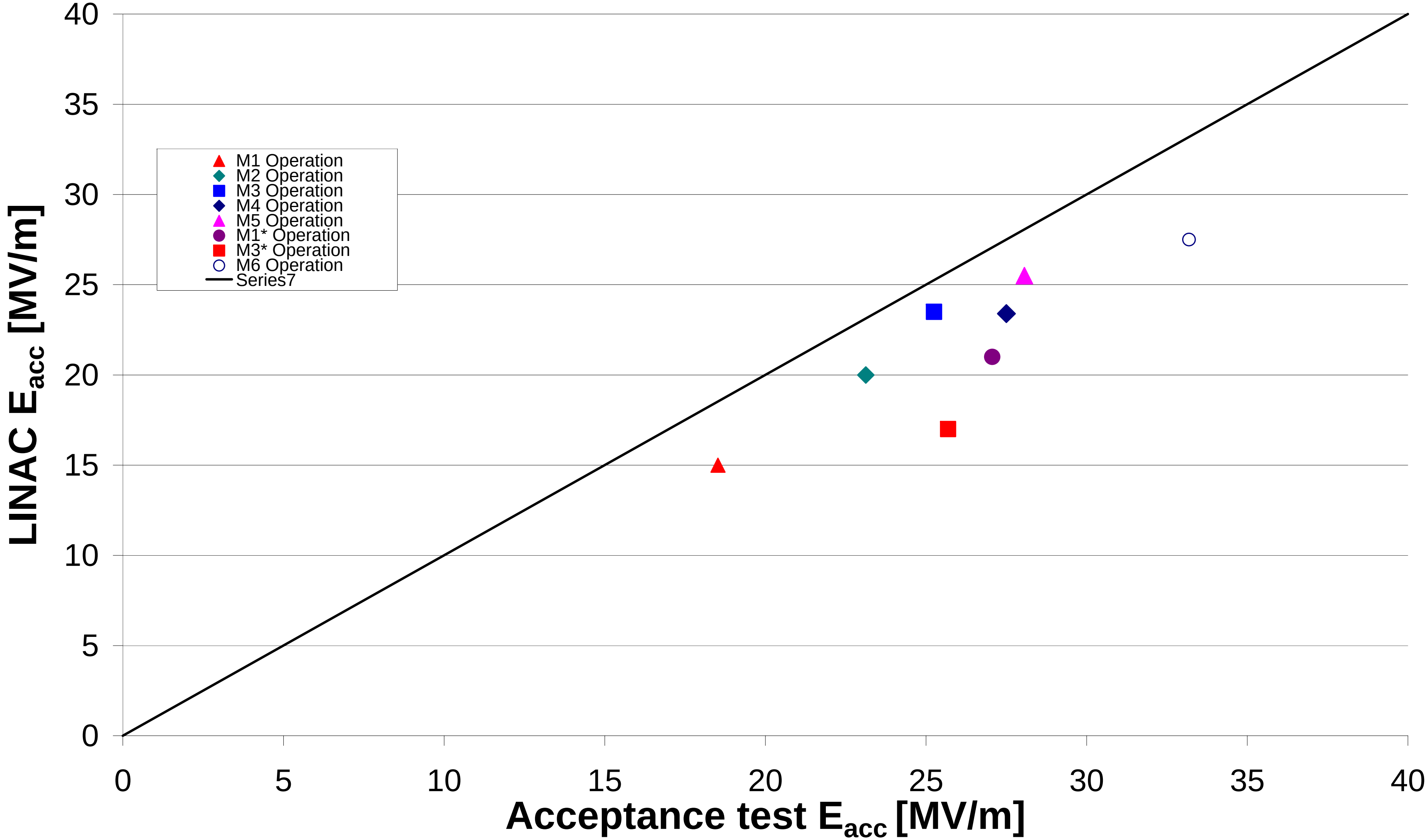
Backup Slides or Garbage…

LINAC vs. Vertical (Individual Cavities)

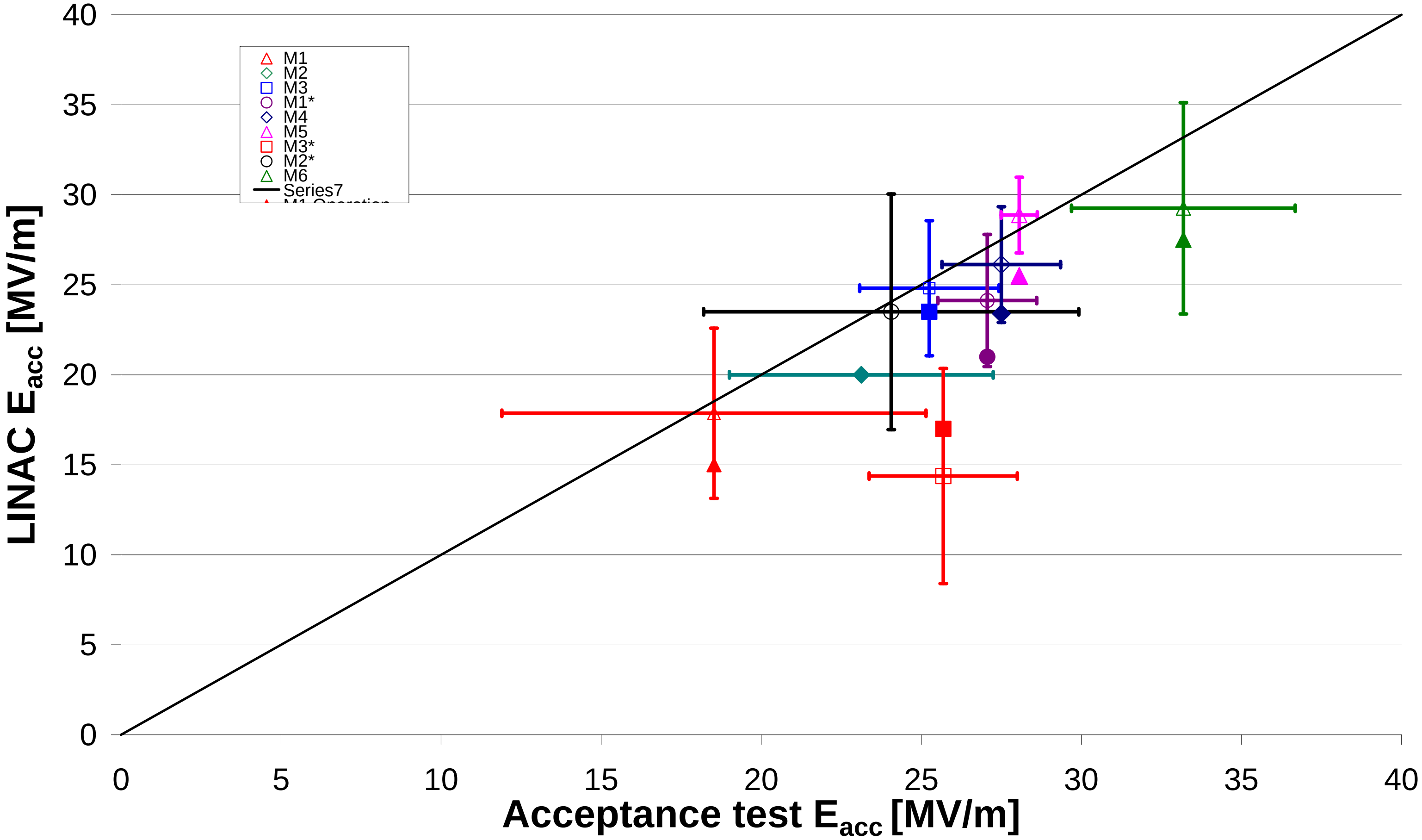
- Some cavities power limited
  - Esp. M5
- Coupler limited
  - M2
  - M4/C3
- Only module measurement available
  - M2



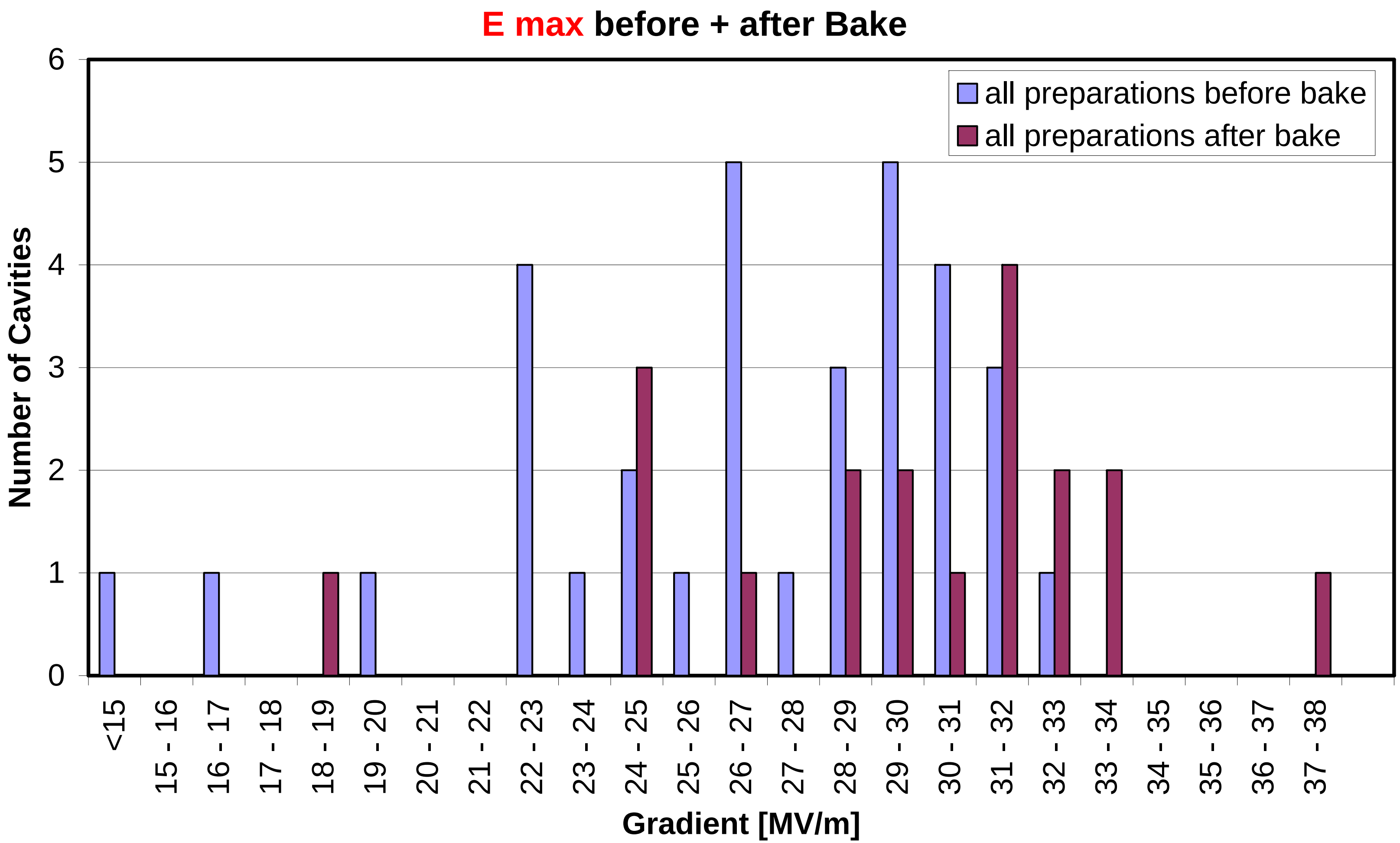
LINAC vs. Vertical (Module Max. Operational Gradient)



LINAC vs. Vertical (Cavity Average and Module Max. Operational)



DESY 4th Production (D. Reschke)



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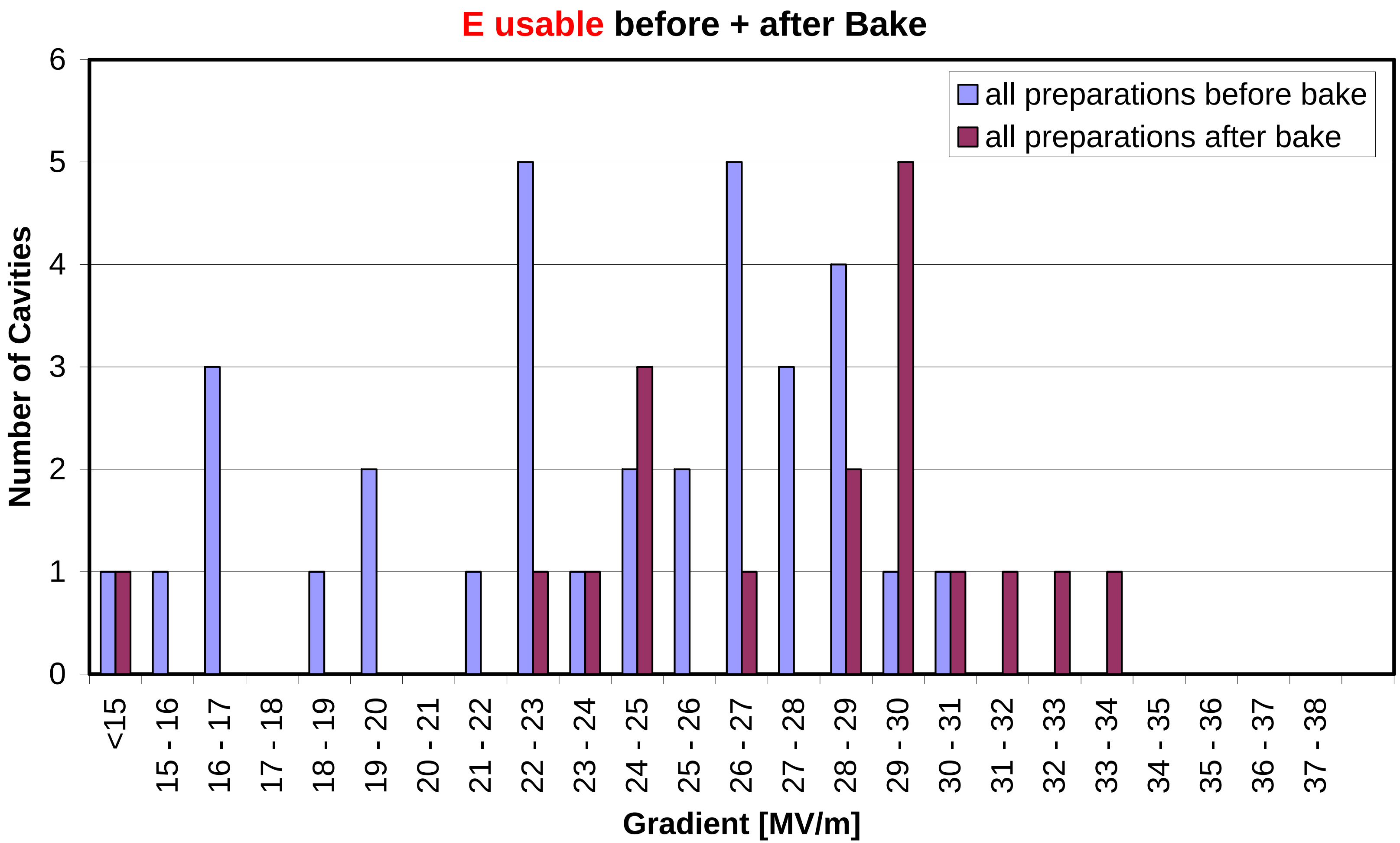
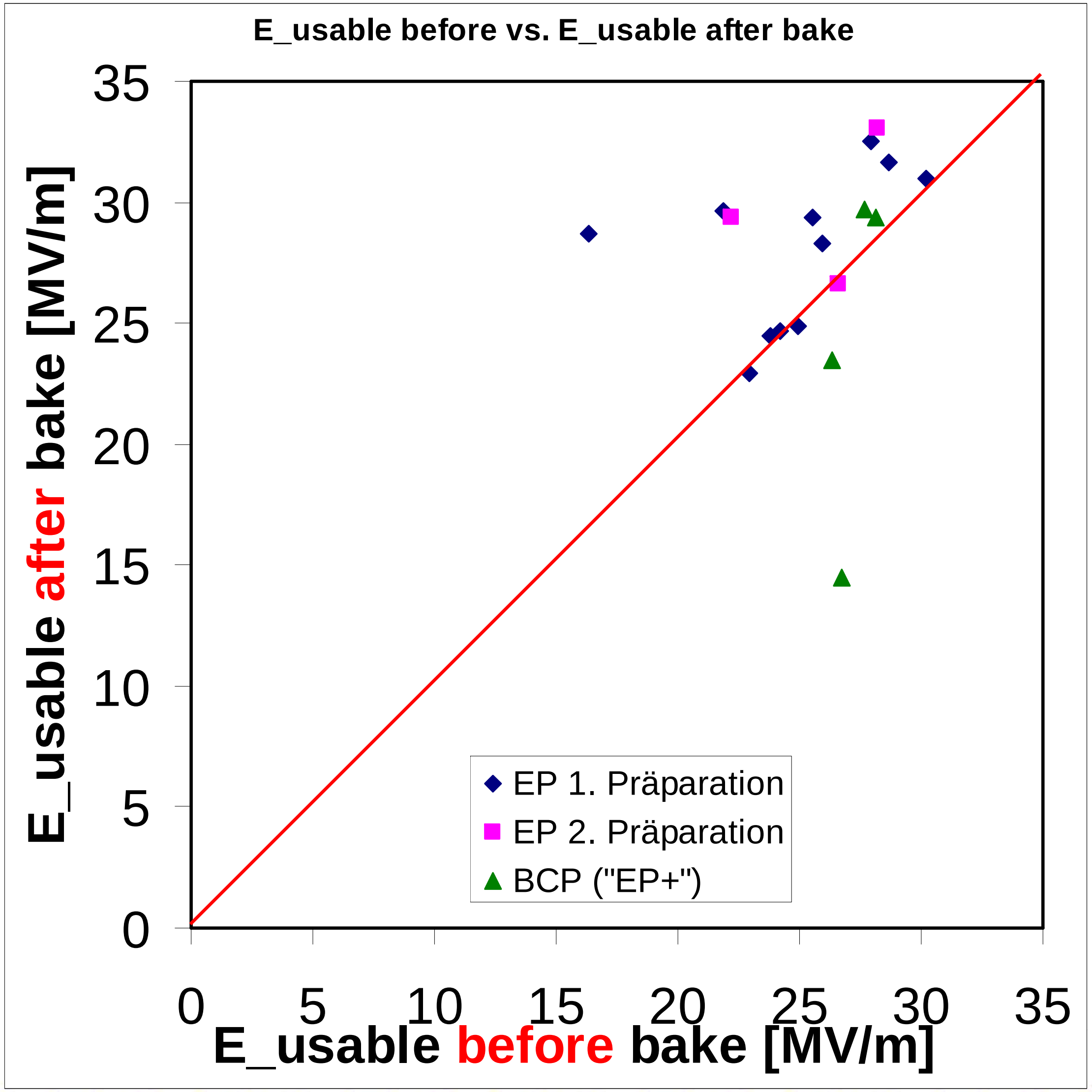
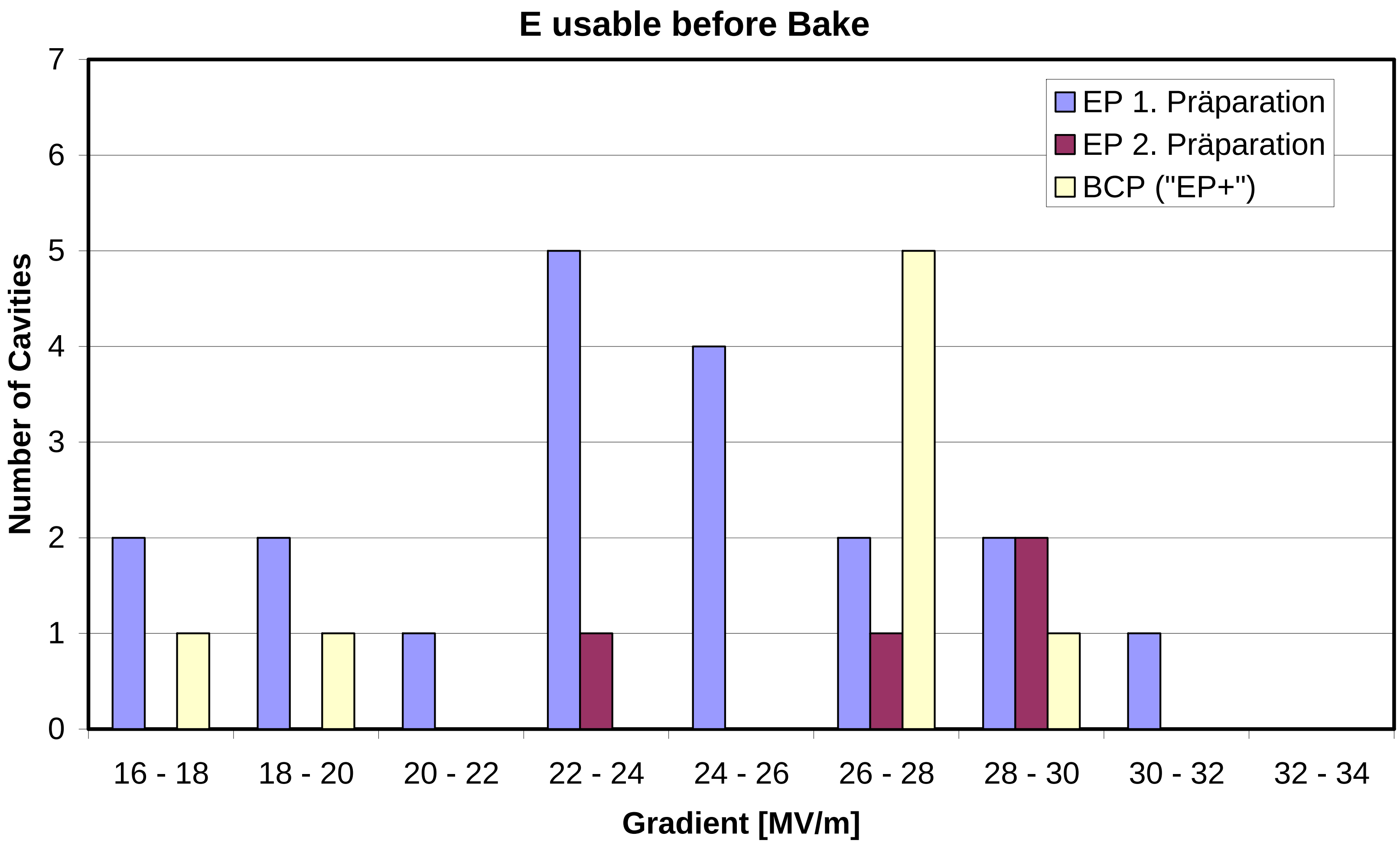


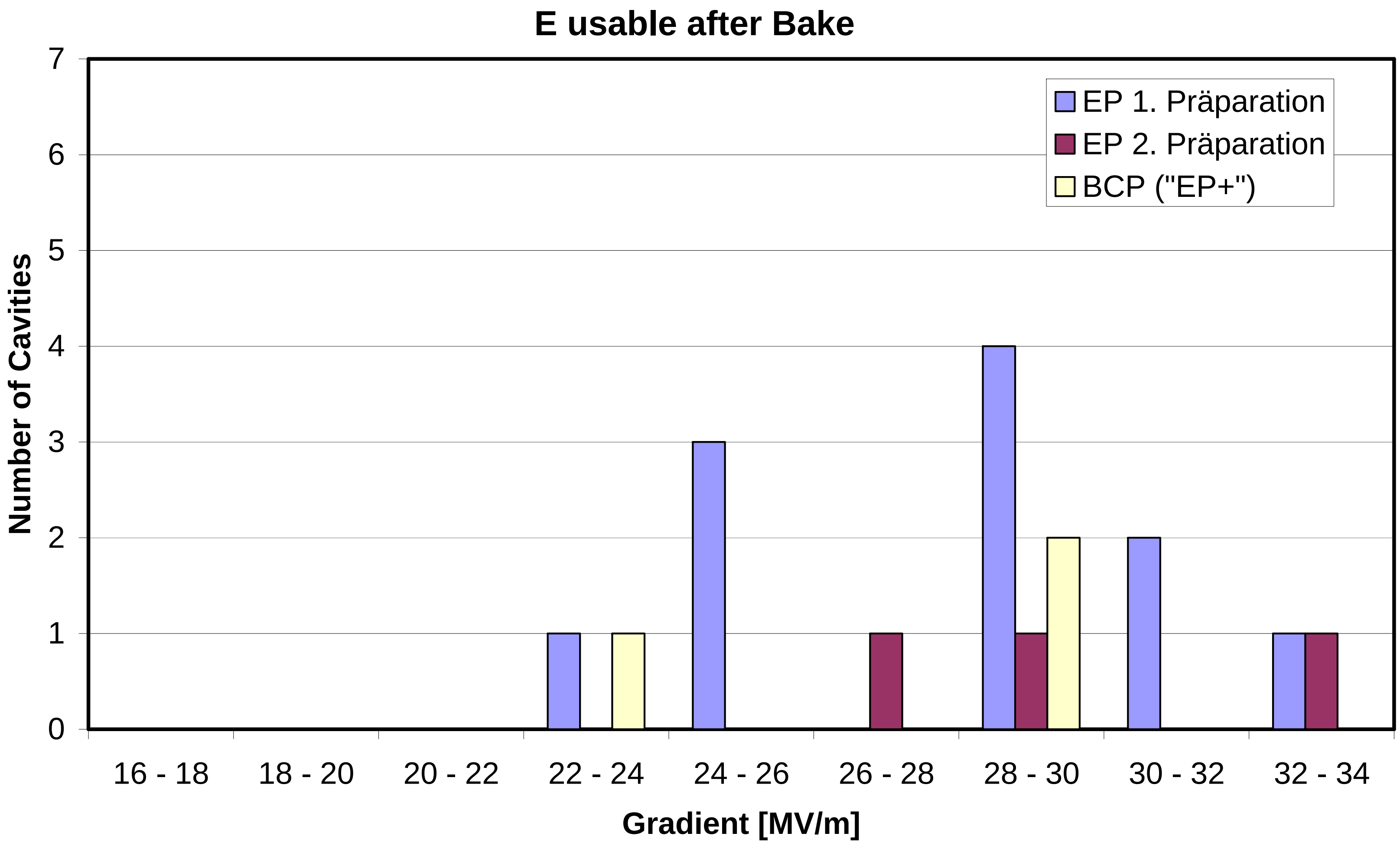
DESY 4th Production (D. Reschke)



DESY 4th Production (D. Reschke)

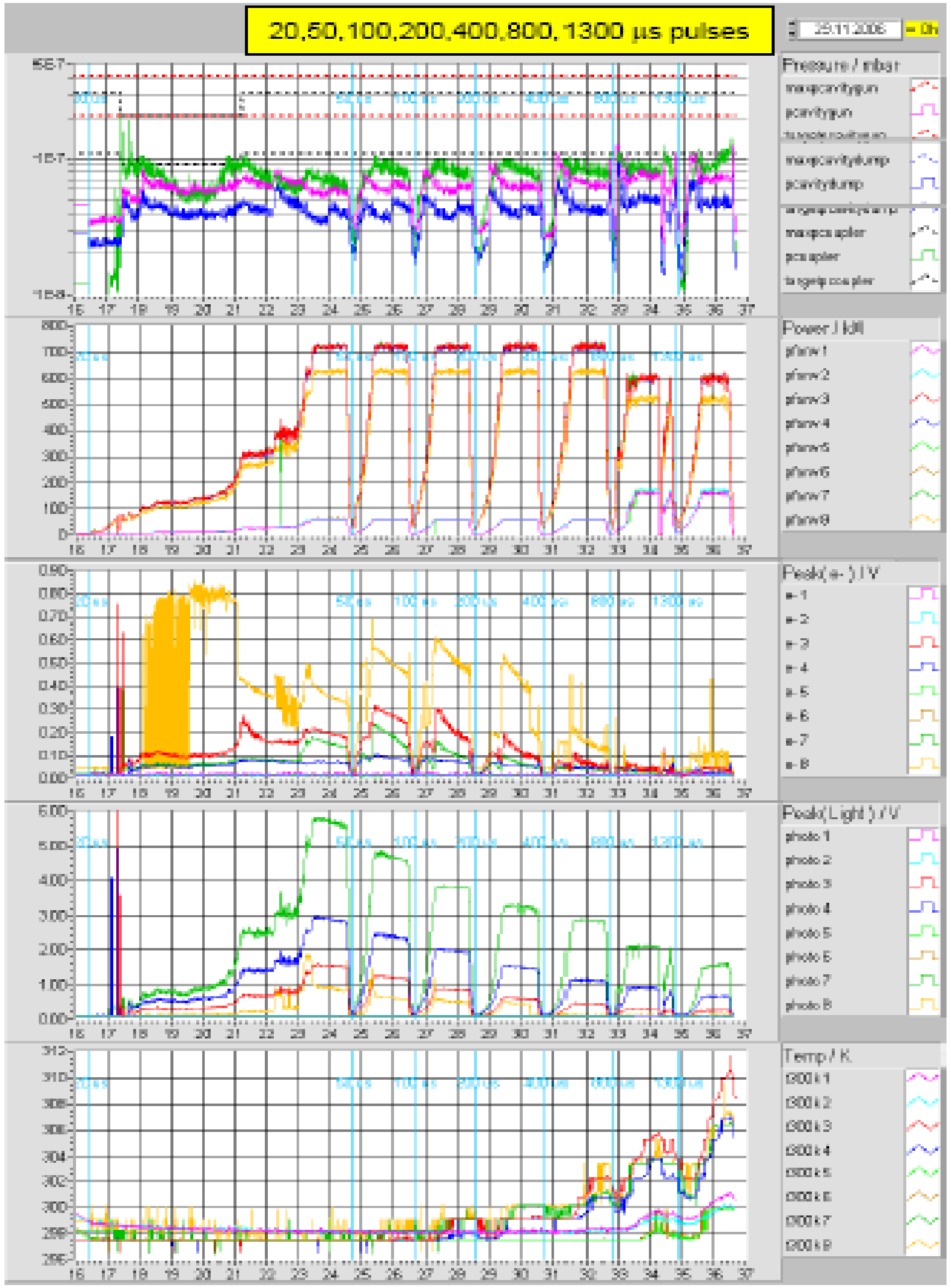


DESY 4th Production (D. Reschke)



Second Set of Coupler

D. Kostin



Input RF couplers 3,4,7,8 warm conditioning

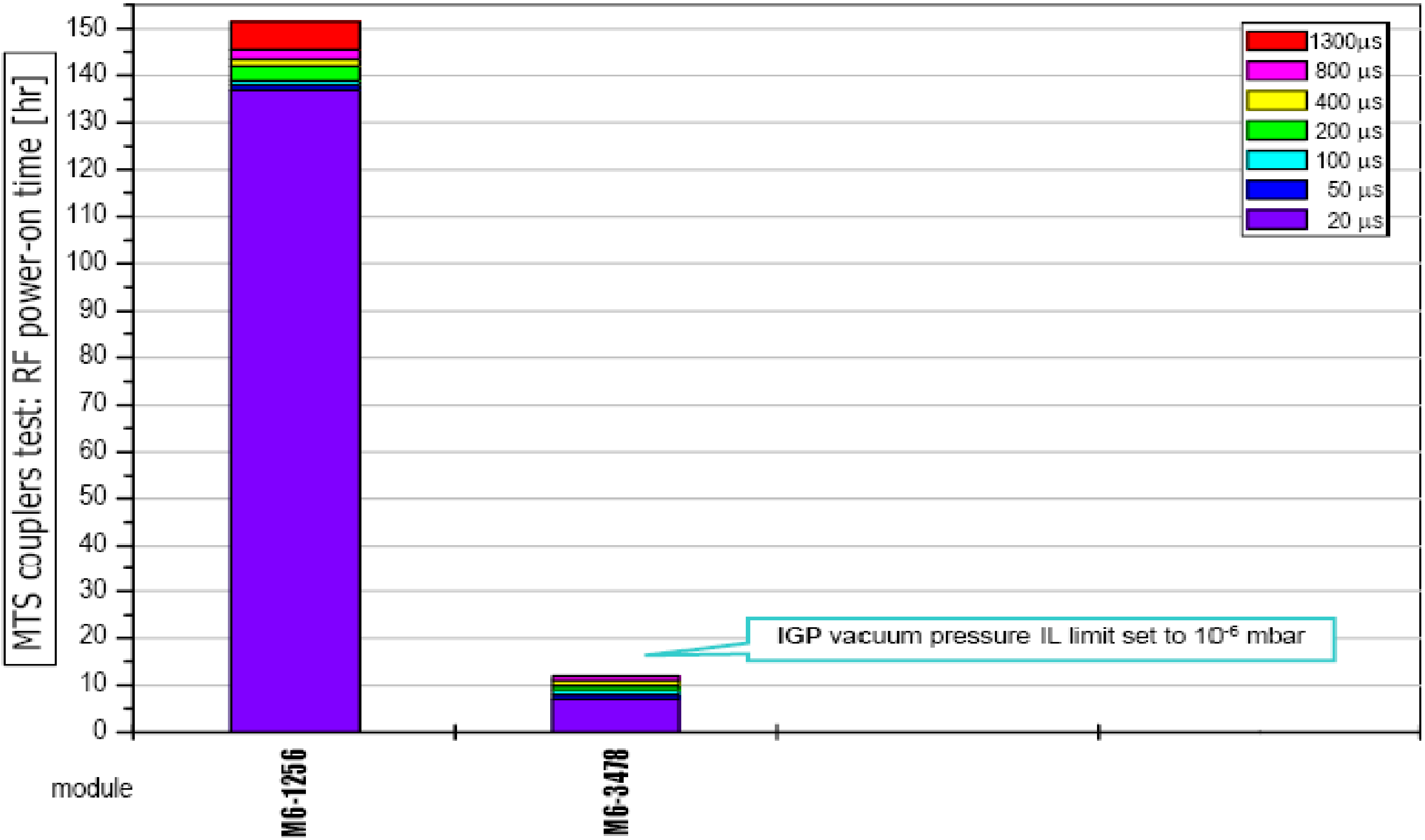
Setting of the higher IGP (pumping speed 60 l/s) vacuum pressure interlock limit (7V: 10^{-6}mbar) as well as conditioning the couplers at higher pressure (like at horizontal cavity cryostat test stand: 1..3x10^{-7} mbar) allows for shorter couplers conditioning time.

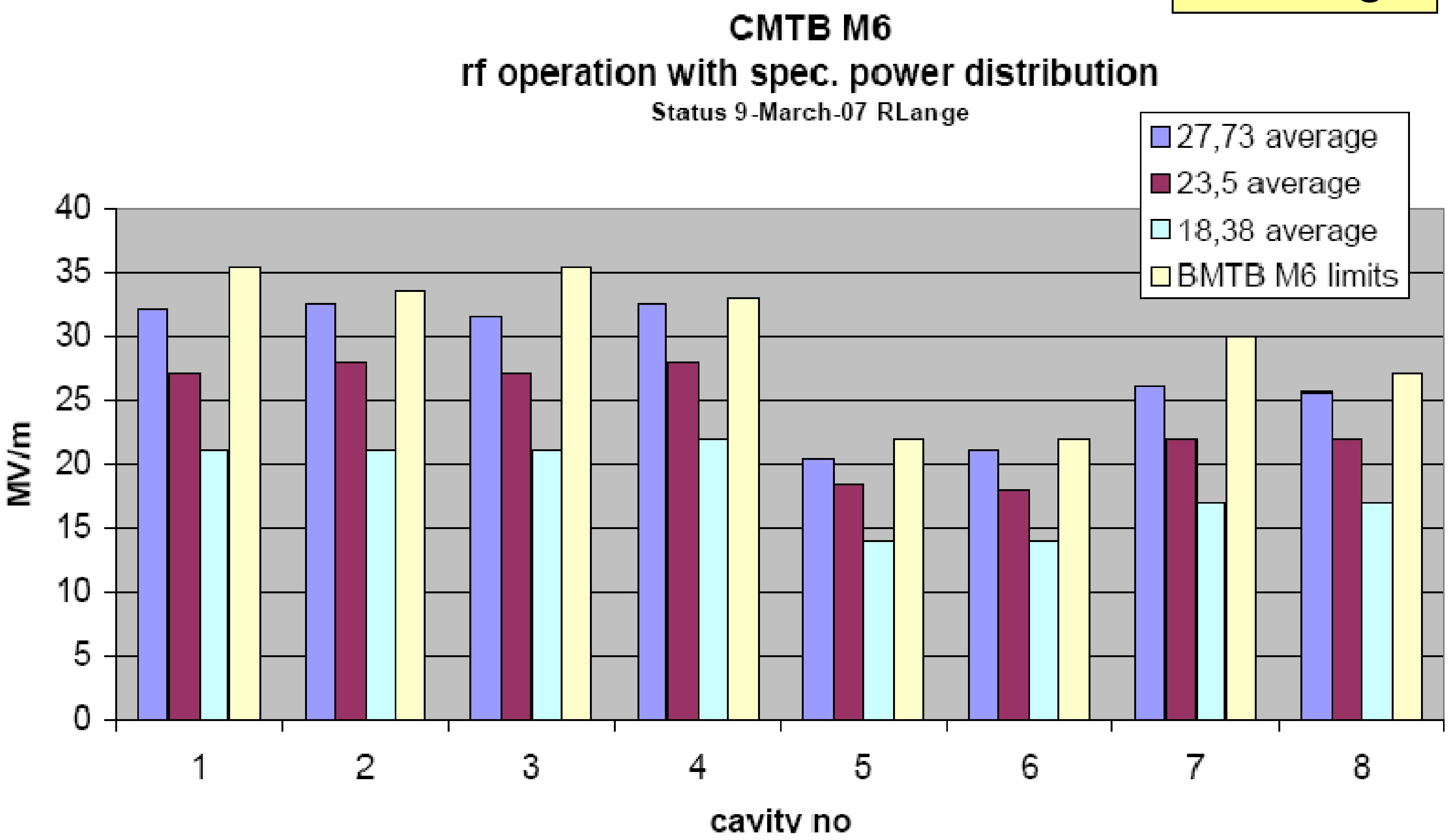
The IGP IL limit was initially set to 5V: 7x10^{-6} mbar, at Horizontal test stand it is set to 7.5V: 2x10^{-6} mbar.

M6 Coupler Processing

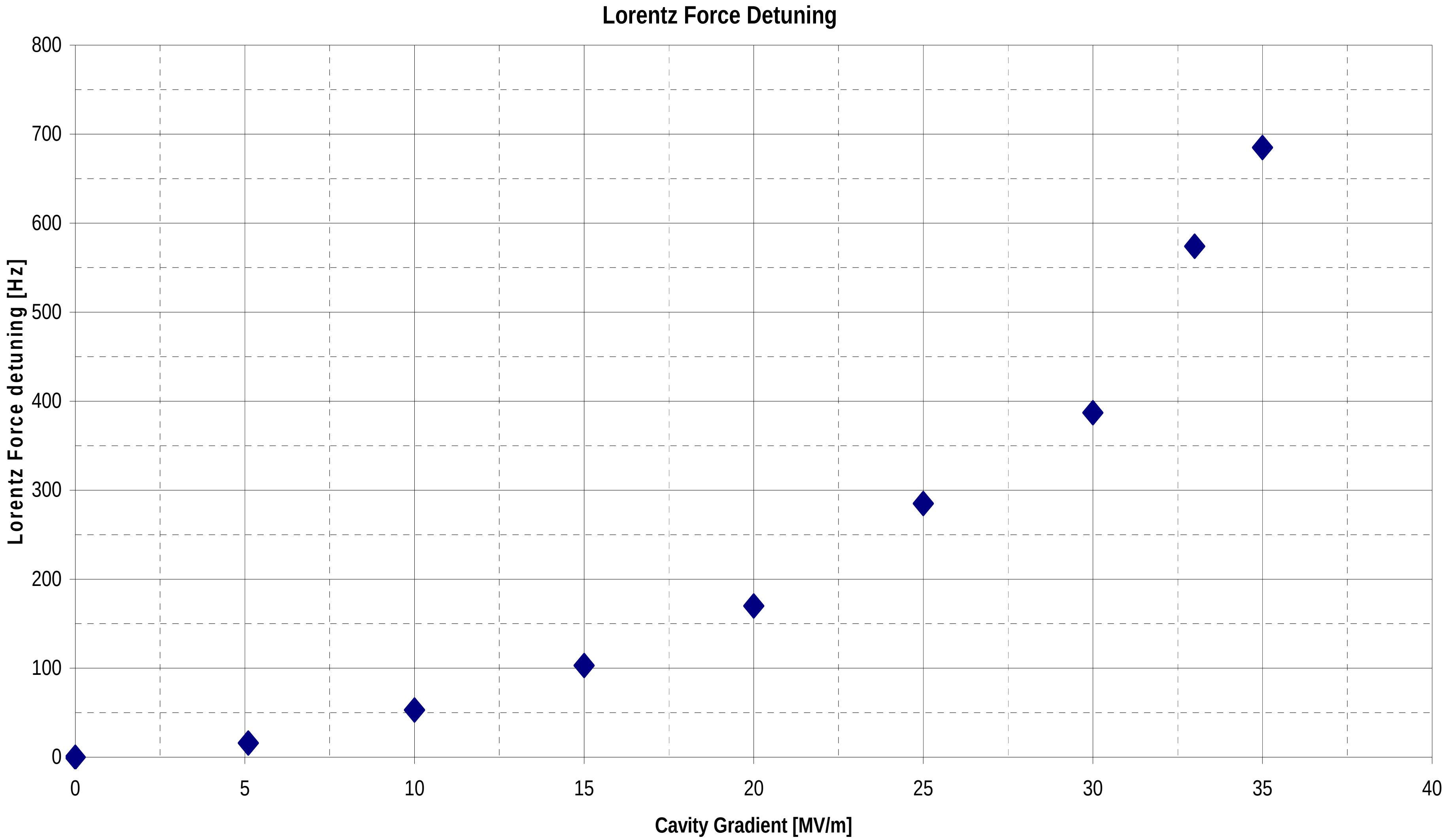
D. Kostin

RF power rising time for different pulse lengths during the couplers conditioning:



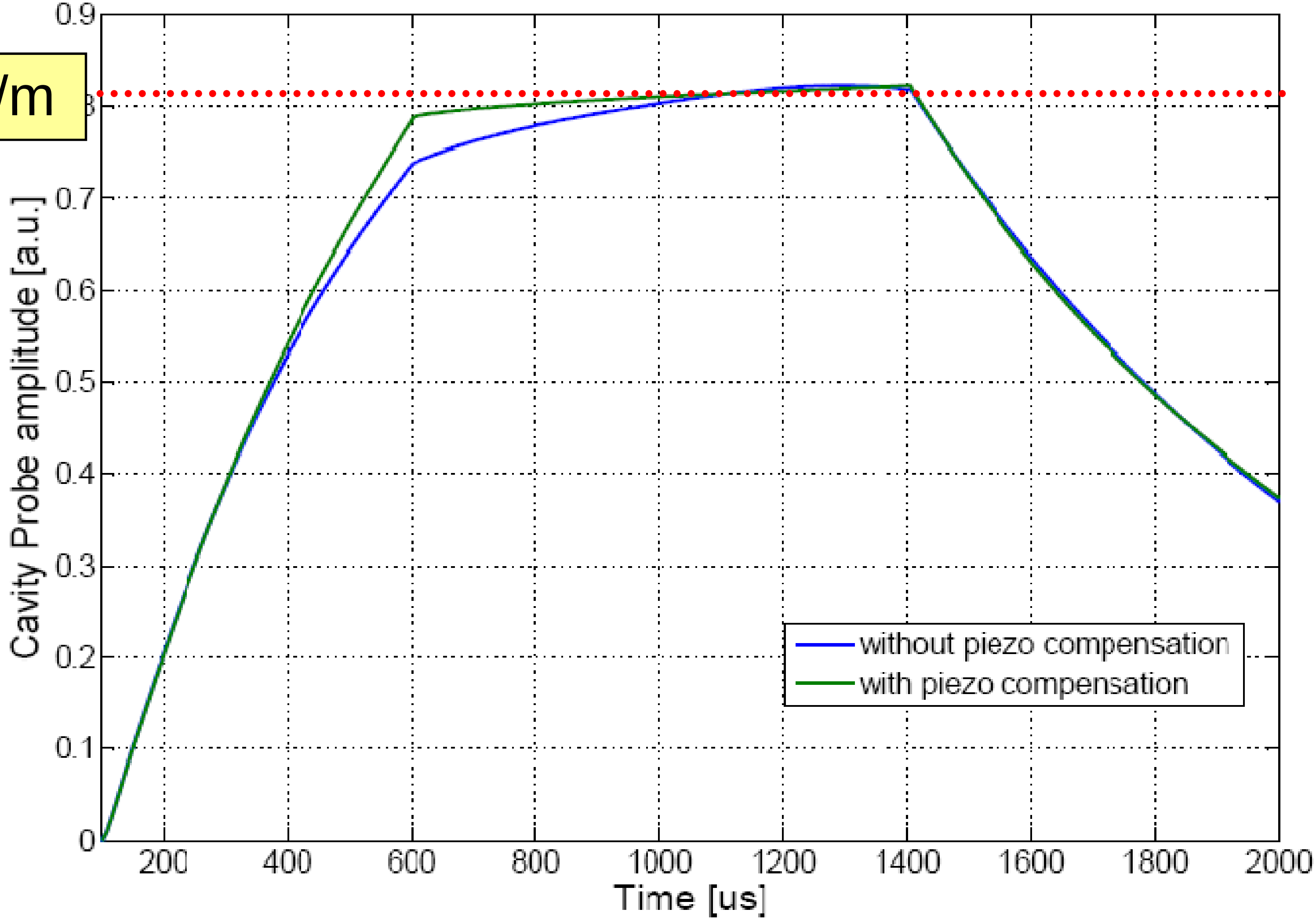

CMTB M6
rf operation with spec. power distribution
Status 9-March-07 RLange
27,73 average
23,5 average
18,38 average
BMTB M6 limits
MV/m
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
cavity no

Example: Cavity 3

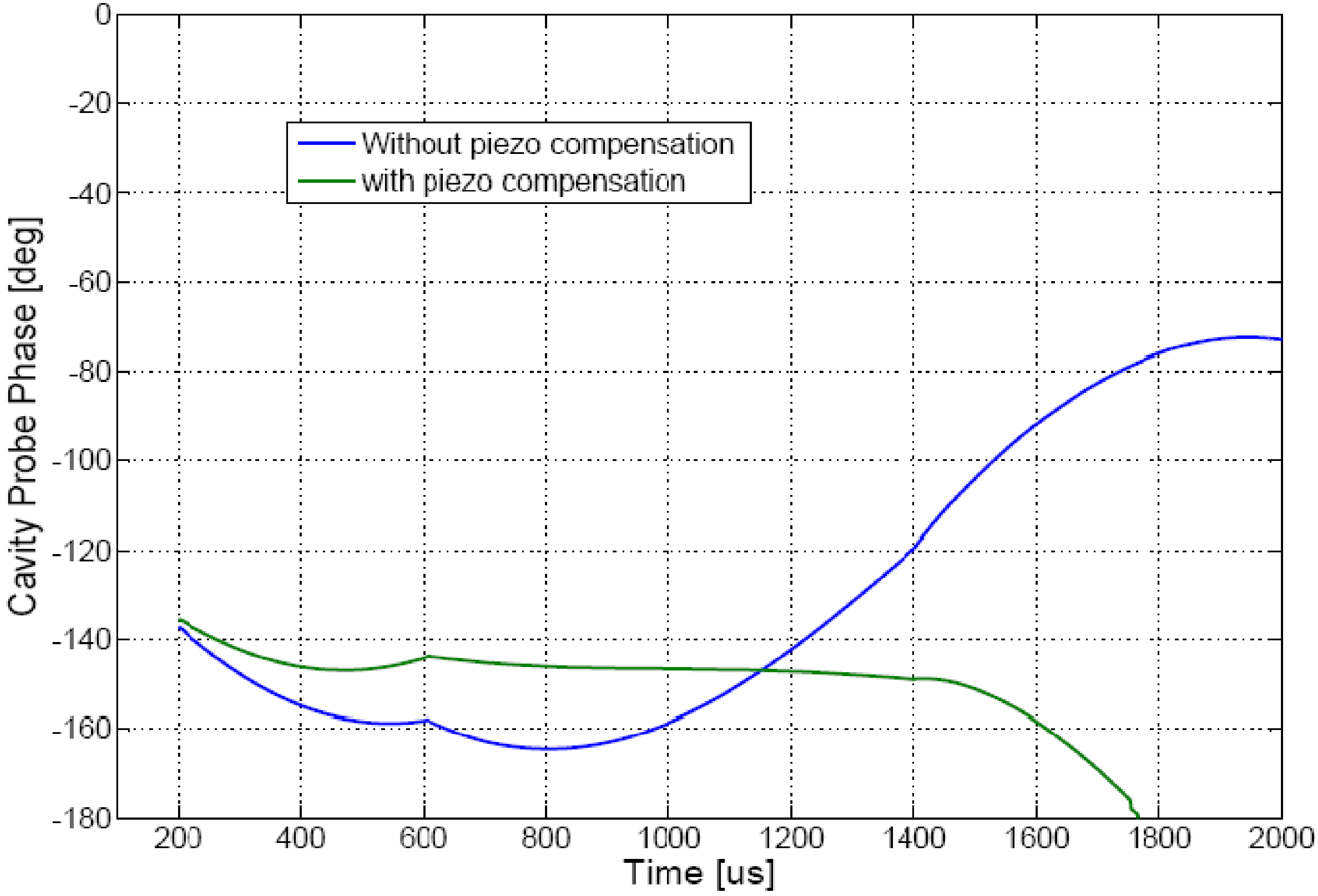


Cavity 3: Gradient

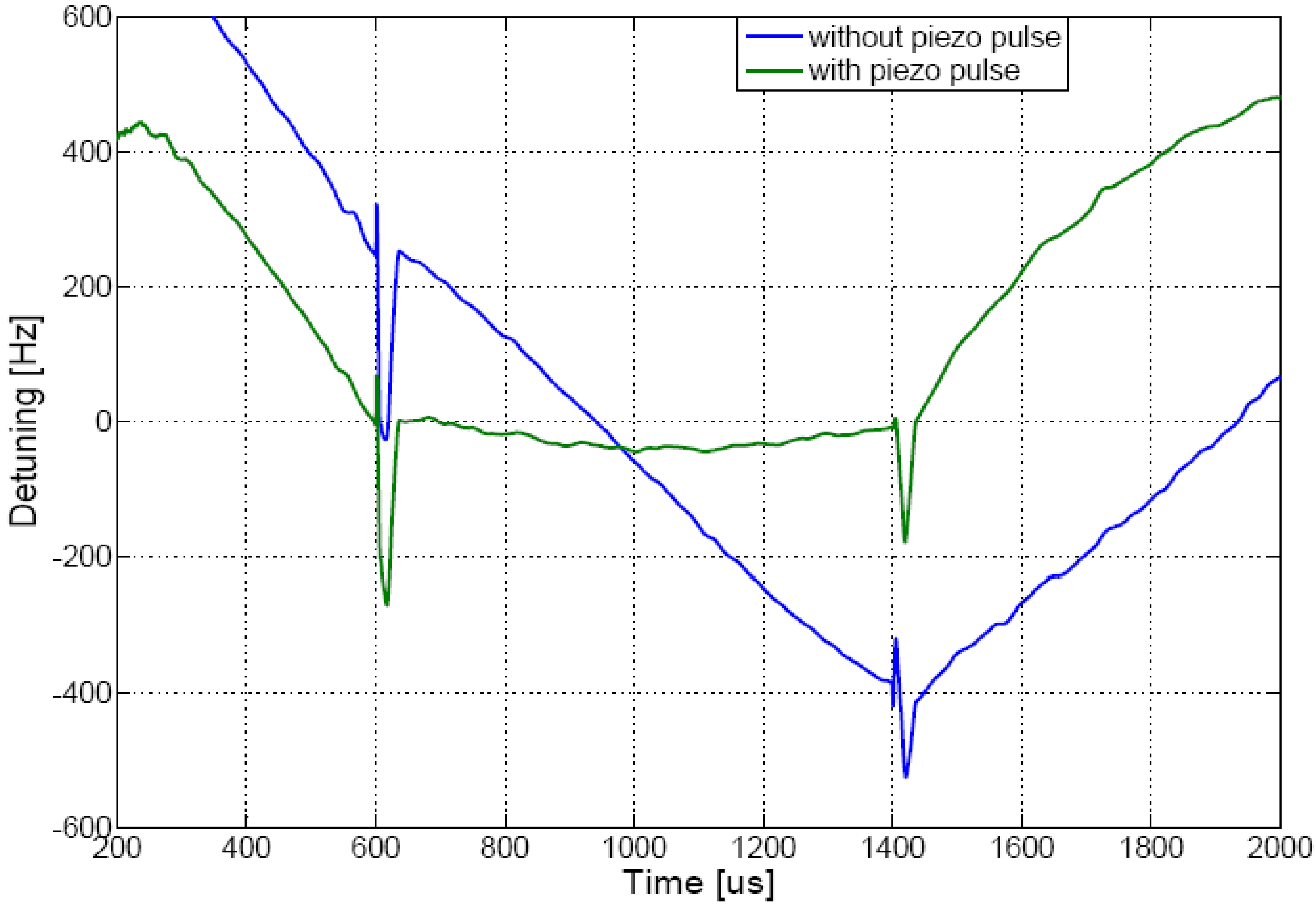
35 MV/m



Cavity 3: Phase

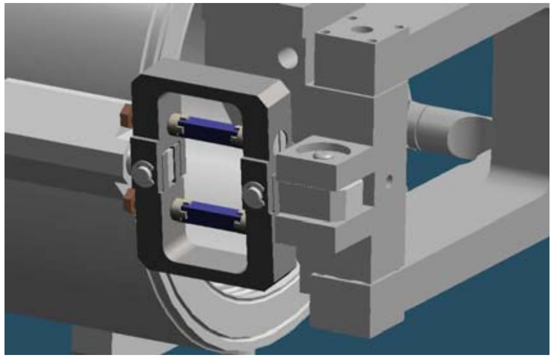


Cavity 3: Detuning



Fast Tuner Tests

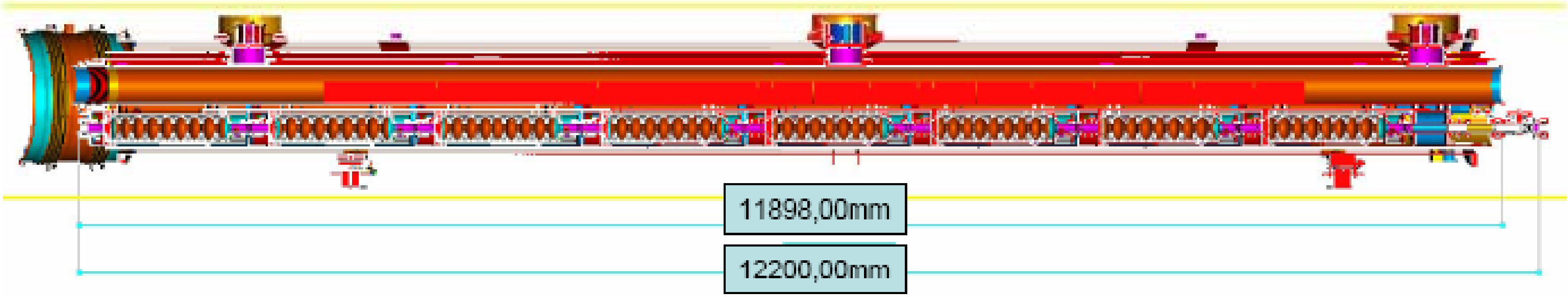
(R.Paparella –INFN, K. Przygoda – Uni. Lodz, L. Lilje DESY)



- Cavities have two piezos installed
  - **sensor-actuator, redundancy**
- Technical remark
  - **All measurements with RF feedforward (no feedback)**
  - **All detunings refer to the 'Flat-Top'-region (beam acceleration) of the RF pulse**
- Detuning rather similar for all cavities
- All cavities (but one) compensated at maximum gradient with simple pulse
  - **E.g. Cavity 3 at 35 MV/m**
  - **Cavity 5 Piezo no mechanical contact at 1,3 GHz**
    - Known problem: Piezo fixture stiffness for large pre-detuning of cavity
      - Currently cavities are compressed, thus exerting an extension of the piezo brackets
      - This will be changed for future cavities, cavities will pull on fixture
        - » N.B.: All ILC tuner designs use cavity that pull.
    - 'Natural' frequency of Cavity 5 after cooldown is 317 kHz above 1.3 GHz, larger compression of cavity needed
    - At 10 kHz above, operational
    - Further investigation ongoing e.g. effects due to thermal cycling
  - **Piezo Voltages within margin**
    - Could also use bipolar operation, but not needed
  - **Delay of piezo can be used to set cavity pre-detuning**

Module TypeIII+

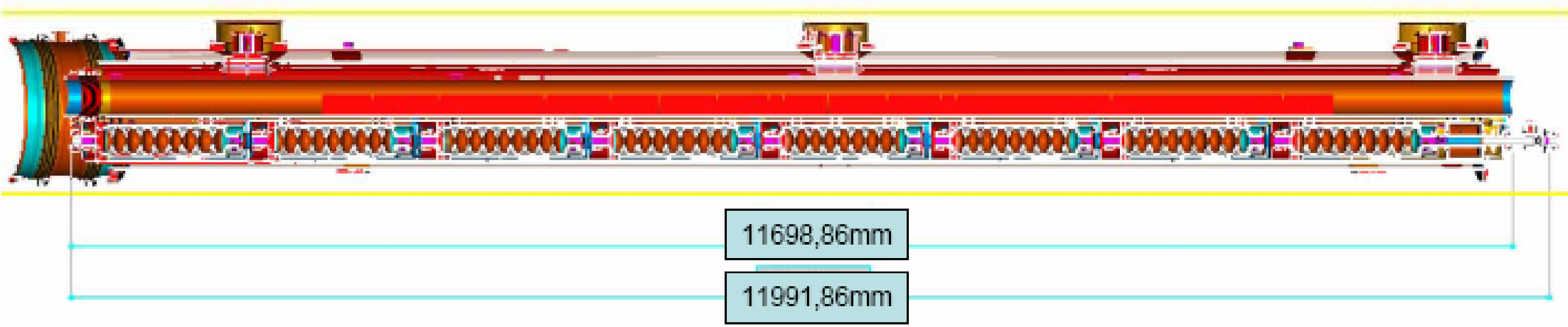
(overview)



3D-JT-File complete cryo module under EDMS*750581

XFEL-Cryomodule

(overview)

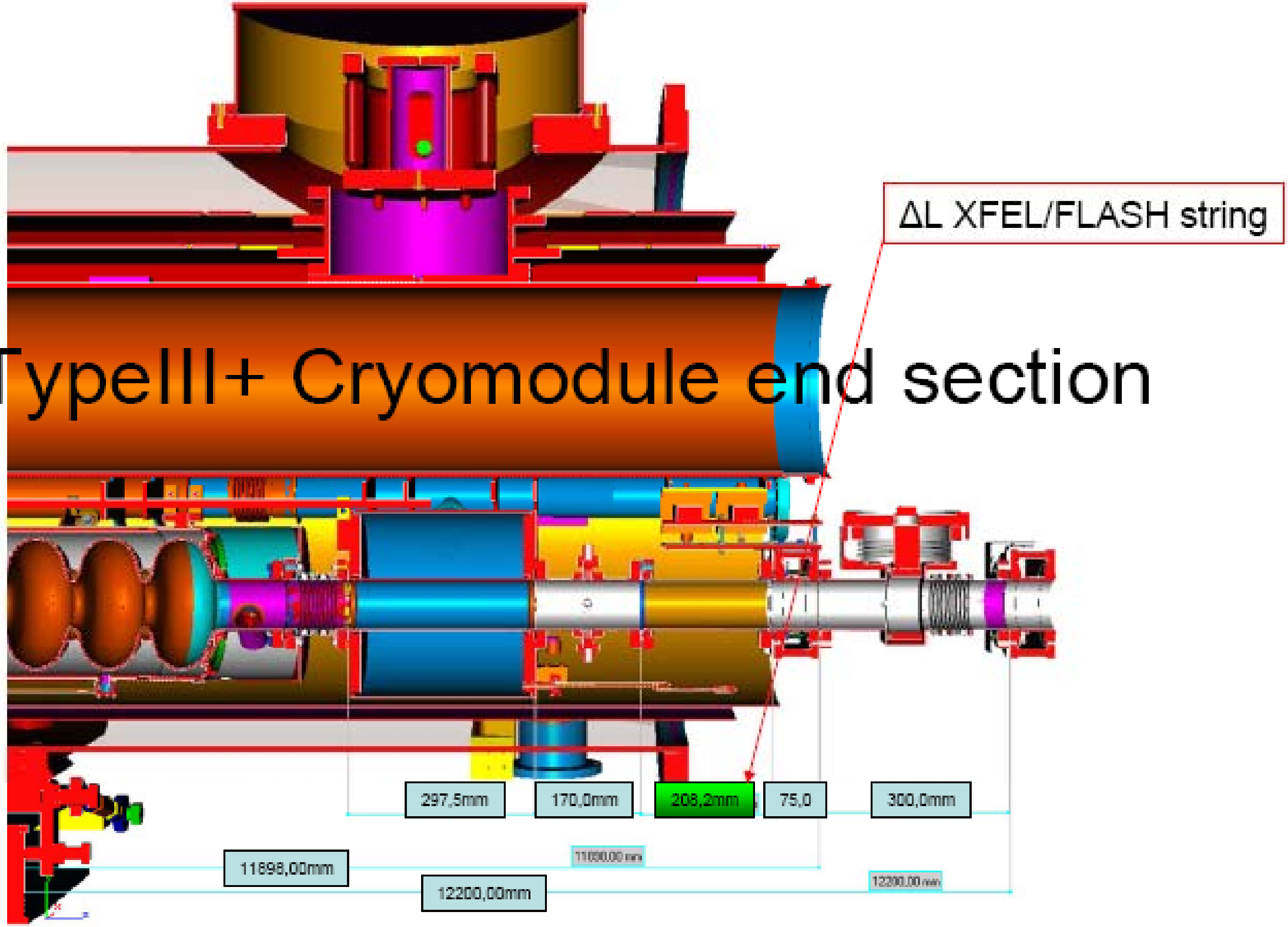


3D-JT-File cavity string under EDMS**752701

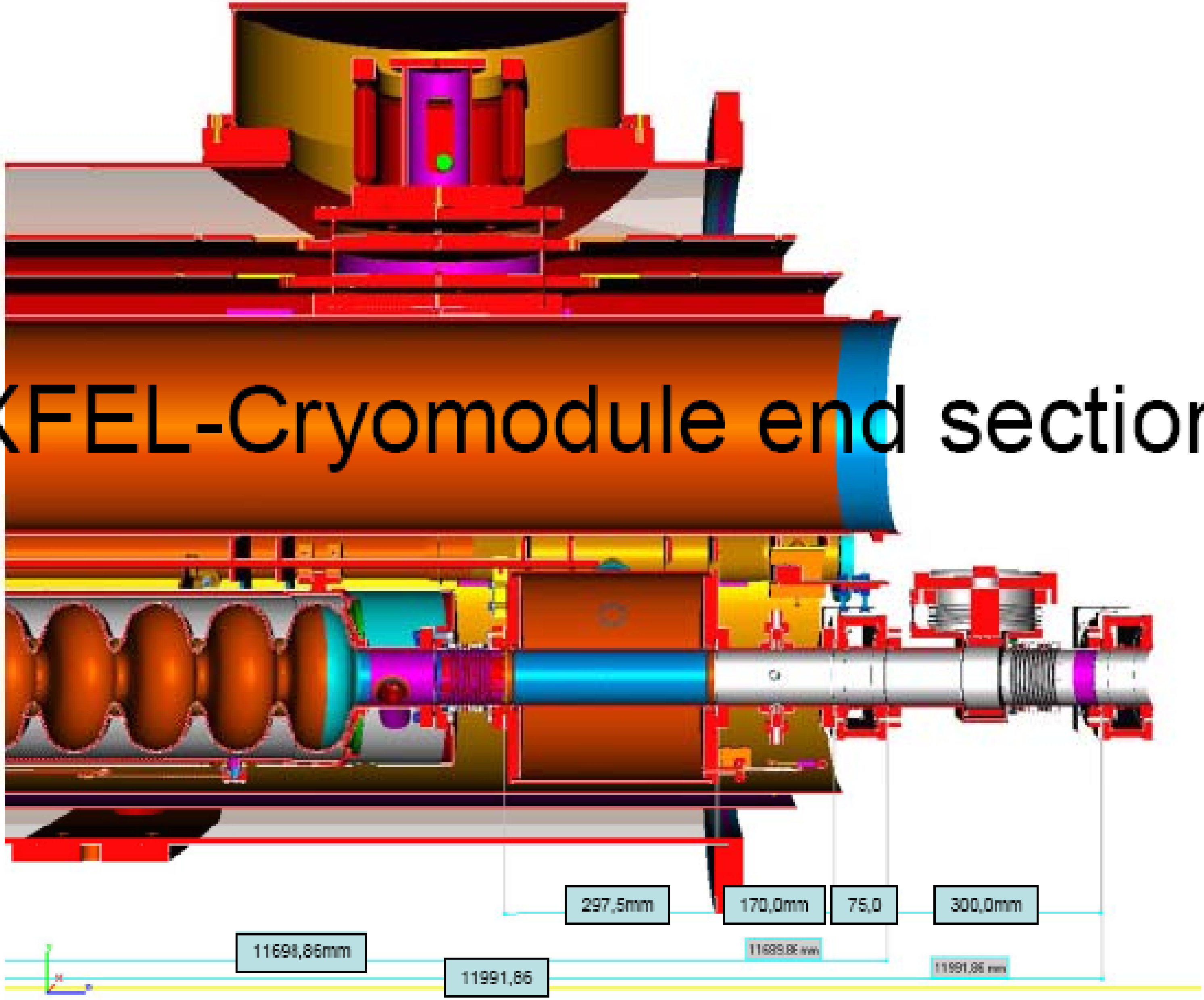
02-Nov-2006

K. Jensch

TypeIII+ Cryomodule end section



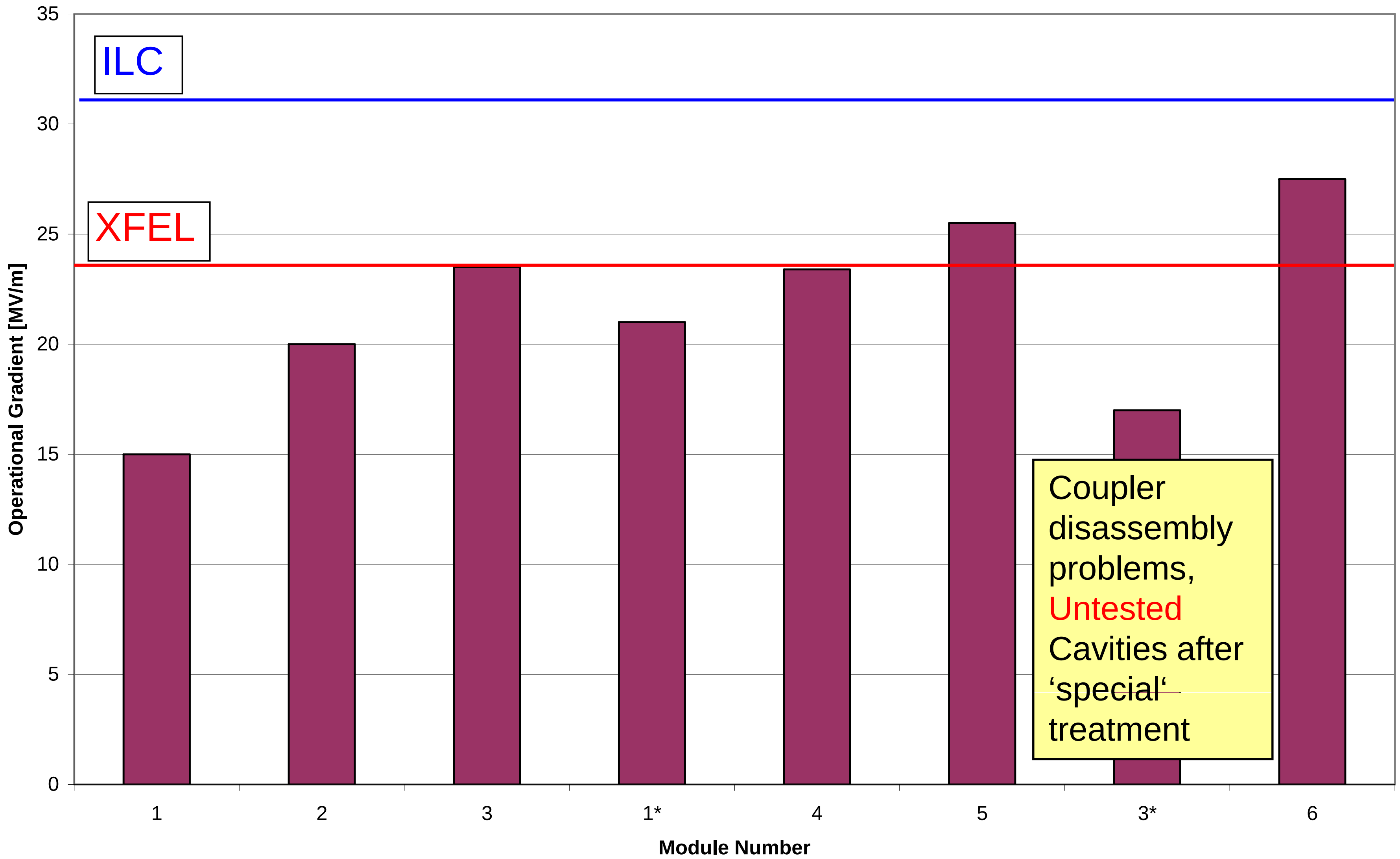
XFEL-Cryomodule end section



02-Nov-2006

K. Jensch

Accelerator Module Operational Gradients (3* included)



Backup Original Slide from Chris: Linac Operation with Variable Tap-Offs (VTOs) and Large Gradient Spread

Chris Adolphsen, SLAC

- Assume cavities produced with flat distribution of sustainable gradients (G) from 22 MV/m to 34 MV/m with <G> = 28 MV/m
- With Qeo optimized for Go = <G>, achieve flat cavity field at G with
  - **Qe = Qeo * ln(2) / ln (1 + G/Go * Qeo/Qe)**
  - **Input Power = Po * (1/4) * (1 + G/Go * Qeo/Qe)^2 * (Qe/Qeo)**
- Requires on average 6.8% more power per rf unit
- Maintain rf unit layout but increase linac length by 31.5/28 -1 = 12.5%
- At 31 MV/m, which is a 3-sigma variation in the mean gradient of an half rf unit, have same 16% tuning overhead as present design at 33 MV/m.
- Considering all changes, ILC cost increases by about 7%