international linear collider

R&D on Cavity Integration and Test

H. Hayano, 05192011

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S1-Global Cryomodule Test

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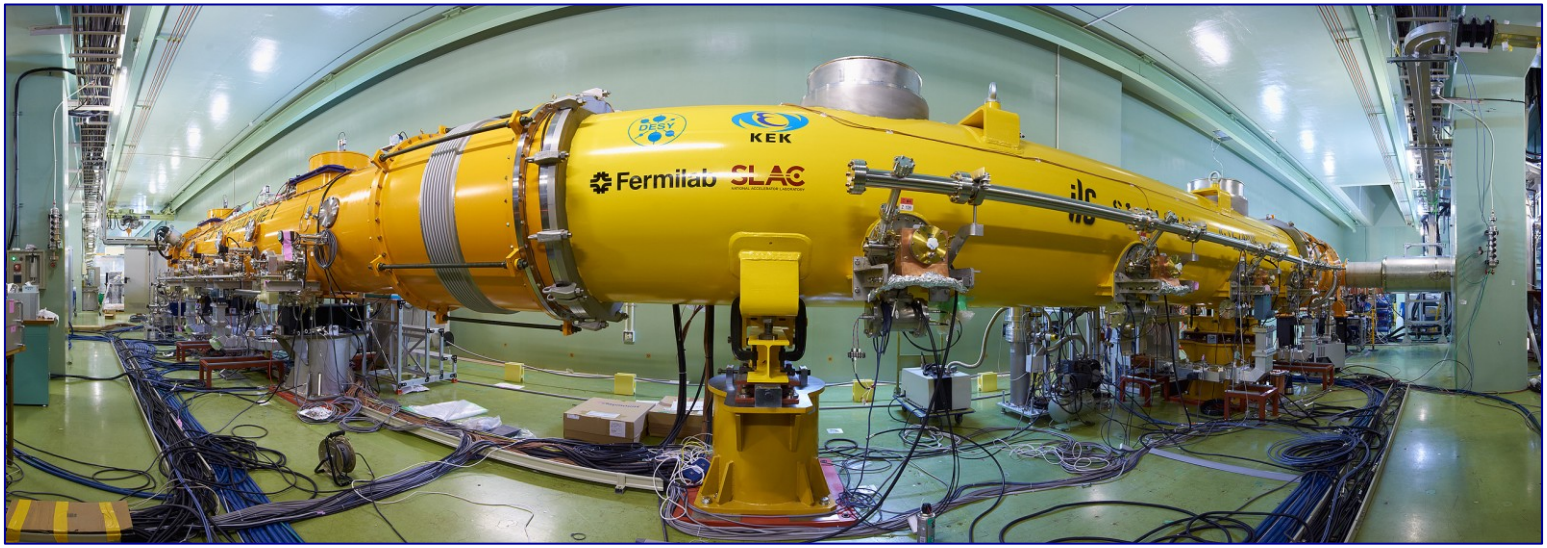
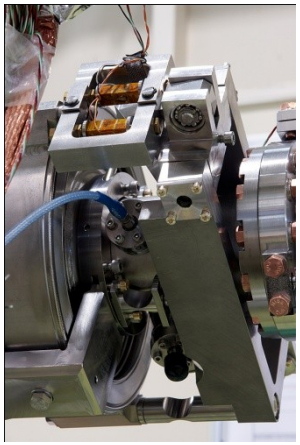


Cavities, Tuners, Couplers in S1-G Cryomodule

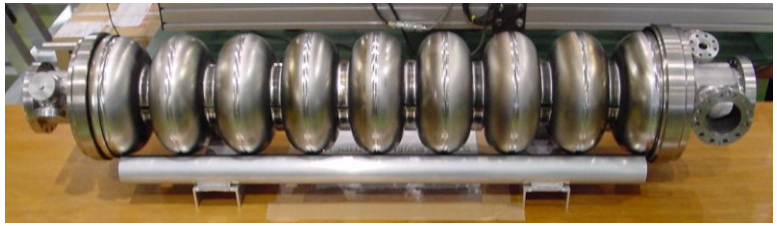
TESLA Cavity (DESY/FNAL)

Blade Tuner (FNAL)

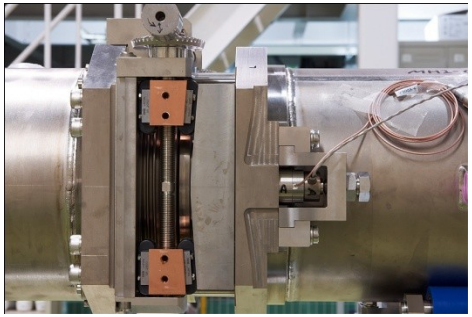


Saclay Tuner (DESY)

TTF-III Coupler (DESY/FNAL)



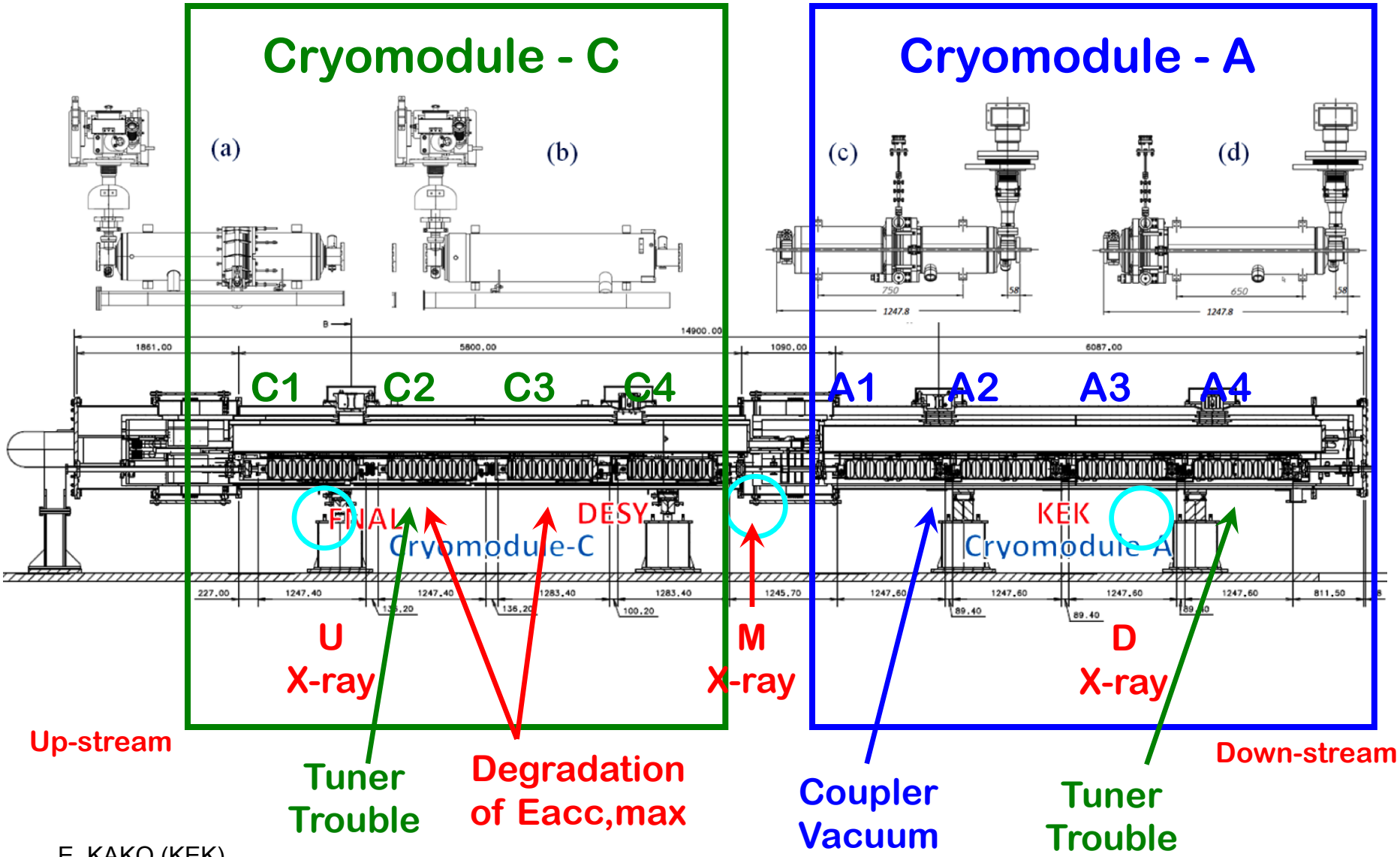
Tesla-like Cavity (KEK)



Slide-Jack Tuner (KEK)

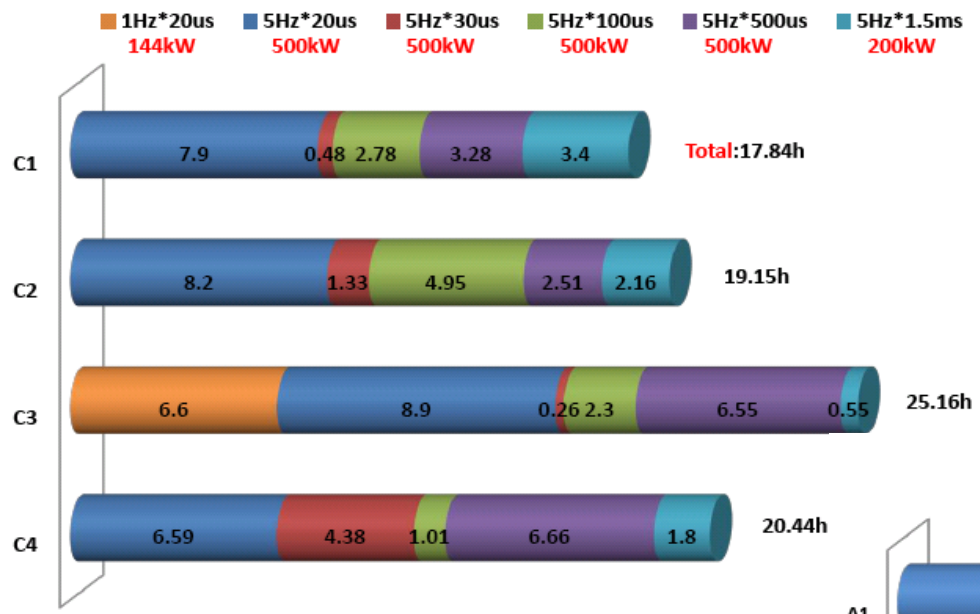
STF-II Coupler (KEK)

Comparison of cavity performance



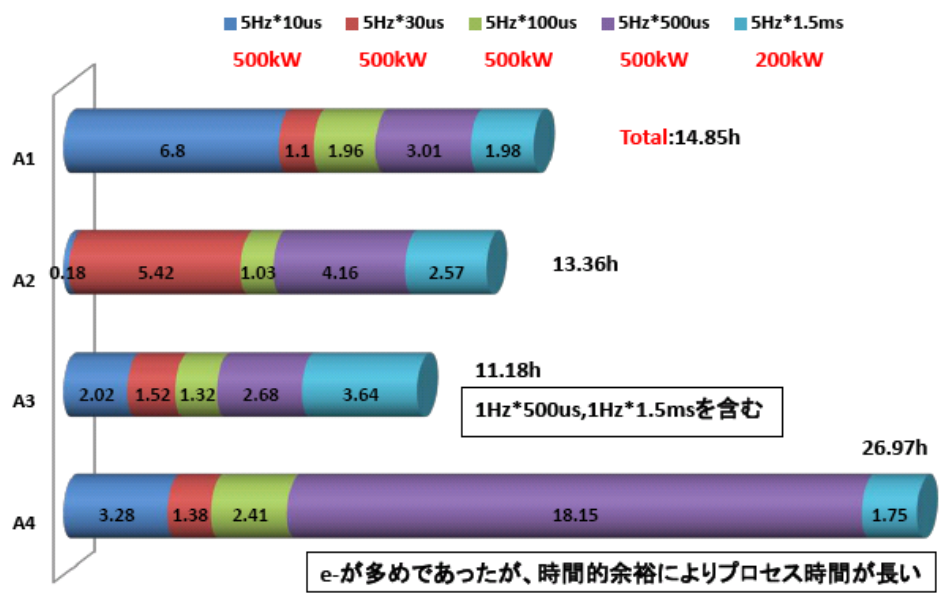
RF processing of input couplers

at room temperature



Cryomodule-C

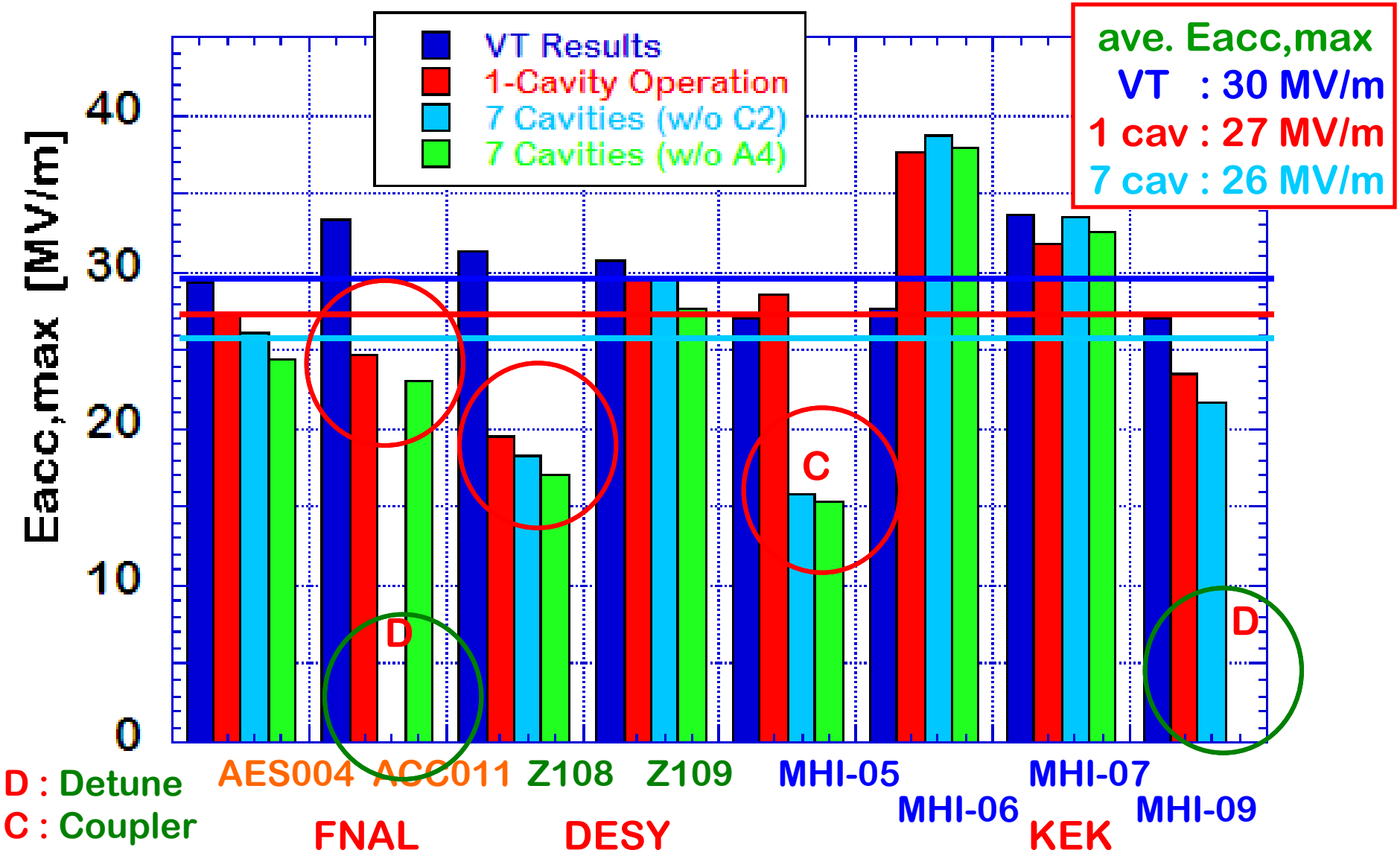
Cryomodule-A



Intentional slow process

RF process time are around 10-20 hours

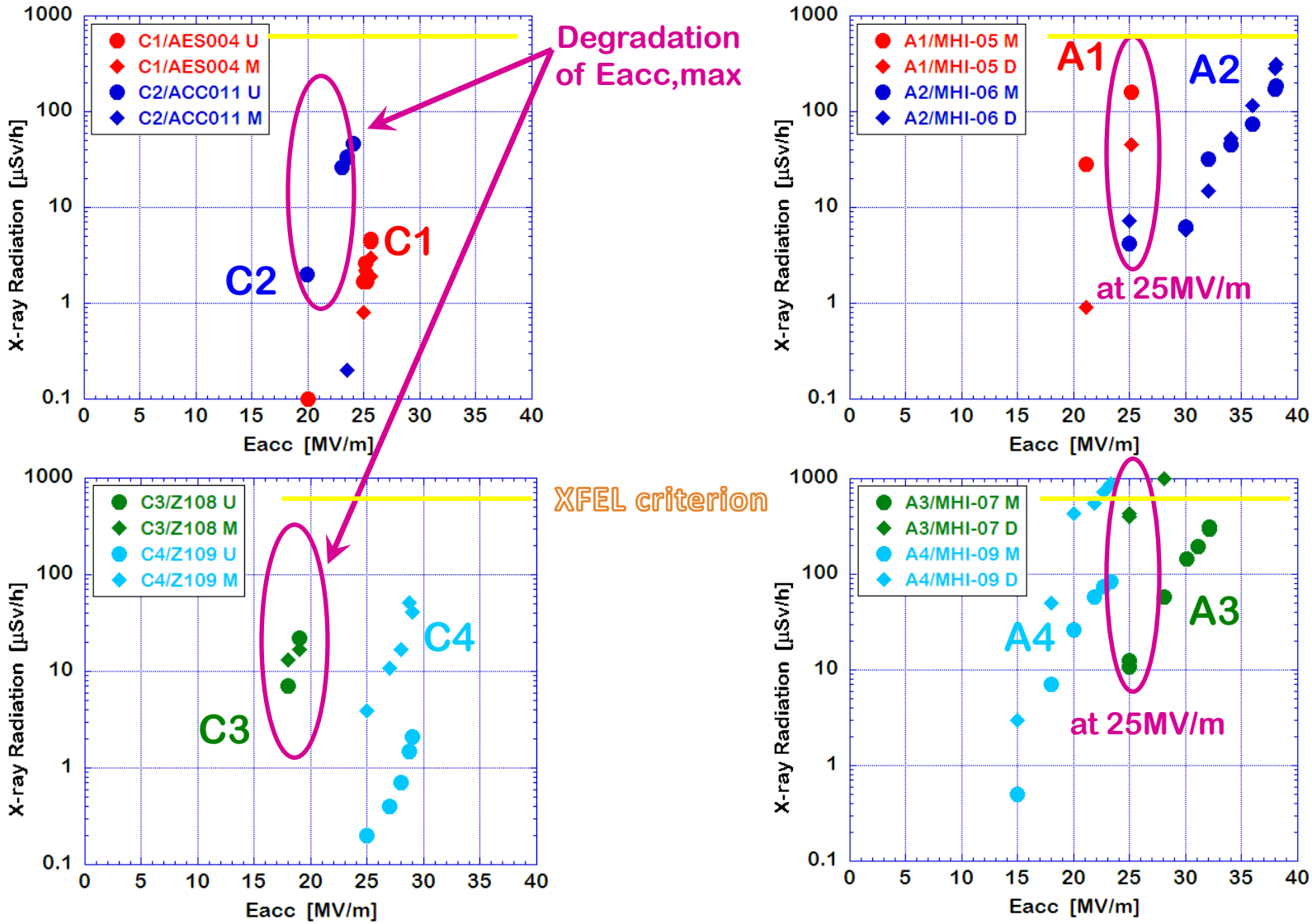
Comparison of cavity performance



○ Performance reduction in two cavities and one coupler

○ Tuner mechanics trouble in two cavities

Cavity performance vs. X-ray emission

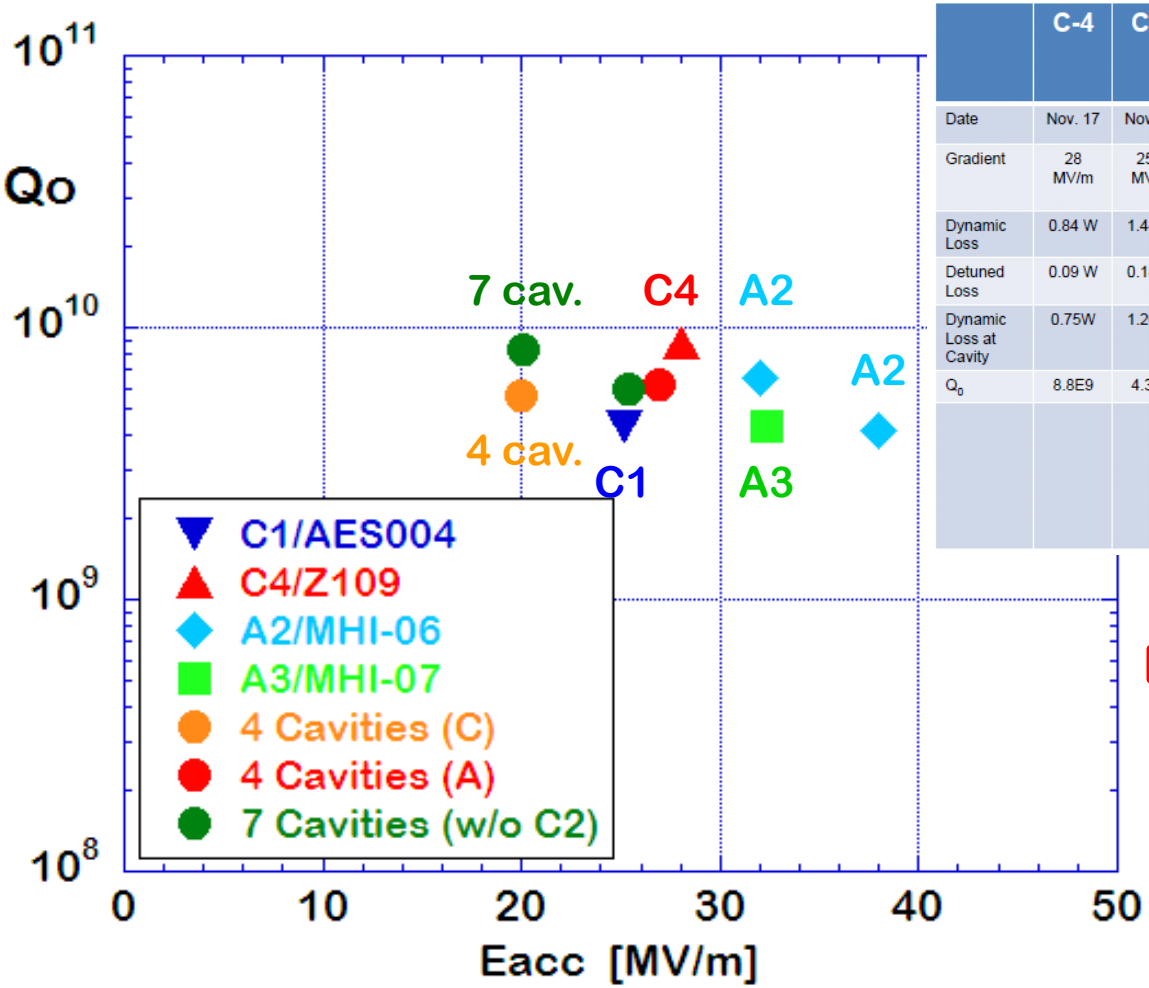


E. KAKO (KEK)
2011' Feb 28

Medium-to-large X-ray emission are observed in every cavity

10^{-2} mGy/min = 10 μSv/min = 600 μSv/h for X-ray

Qo values measured by dynamic loss



Dynamic Loss Measurement

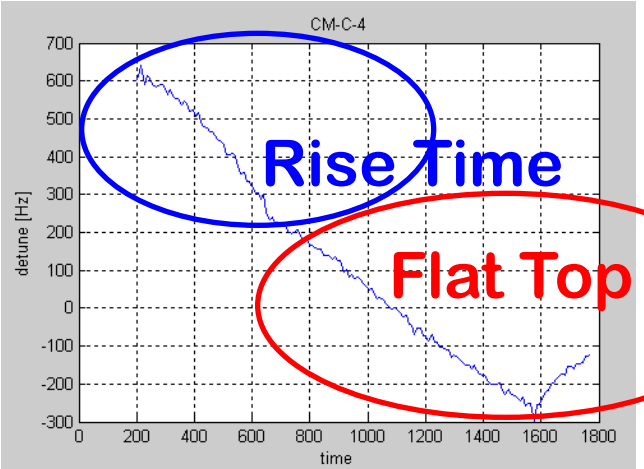
	C-4	C-1	A-3	A-2	A-2	4 C Cavities	4 A Cavities	4 C Cavities	4 A Cavities	7 Cavities	7 Cavities
Date	Nov. 17	Nov. 19	Nov. 23	Nov. 24	Nov. 25	Nov. 26	Nov. 30	Dec. 2	Dec. 3	Dec. 9	Dec. 10
Gradient	28 MV/m	25.2 MV/m	32.3 MV/m	38 MV/m	32 MV/m	32 MV/m Detune	32 MV/m Detune	20 .0 MV/m	26.9 MV/m	25.4 MV/m	20.4 MV/m
Dynamic Loss	0.84 W	1.44 W	2.8 W	4.8 W	2.6 W			2.7 W	6.9 W	9.6 W	4.8 W
Detuned Loss	0.09 W	0.18 W	0.7 W	1.8 W	1.2 W	0.5 W	4.6 W	0.2 W	2.5 W	2.6 W	1.6 W
Dynamic Loss at Cavity	0.75W	1.26 W	2.0 W	2.9 W	1.3 W			2.5 W	4.4 W	7.0 W	3.2 W
Q_0	8.8E9	4.3E9	4.3E9	4.2E9	6.5E9						
								C1=22.2 C2=18.9 C3=14.9 C4=24.3	A1=15.8 A2=37.6 A3=32.9 A4=21.4	C1=25.2 C2=NA C3=17.6 C4=28.8 A1=15.3 A2=37.4 A3=32.4 A4=20.9	C1=20.1 C2=NA C3=14.1 C4=23.0 A1=12.3 A2=30.4 A3=26.0 A4=16.7

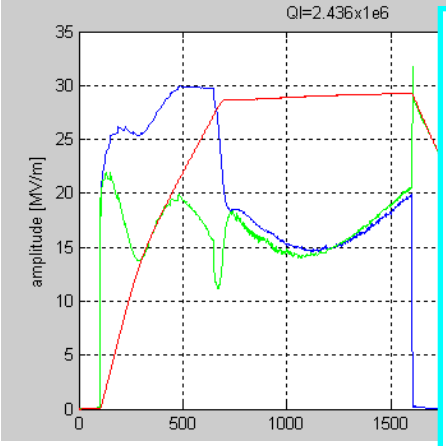
Dynamic loss at input coupler
(Detuning at 32 MV/m)
TTF-III : 0.5 W / 4 couplers
STF-II : 4.6 W / 4 couplers

Cavity Q are rather below than $1x10^{10}$,
KEK coupler have much loss than TTF coupler

Frequency shift due to Lorentz detuning

C4/Z109 (29MV/m)

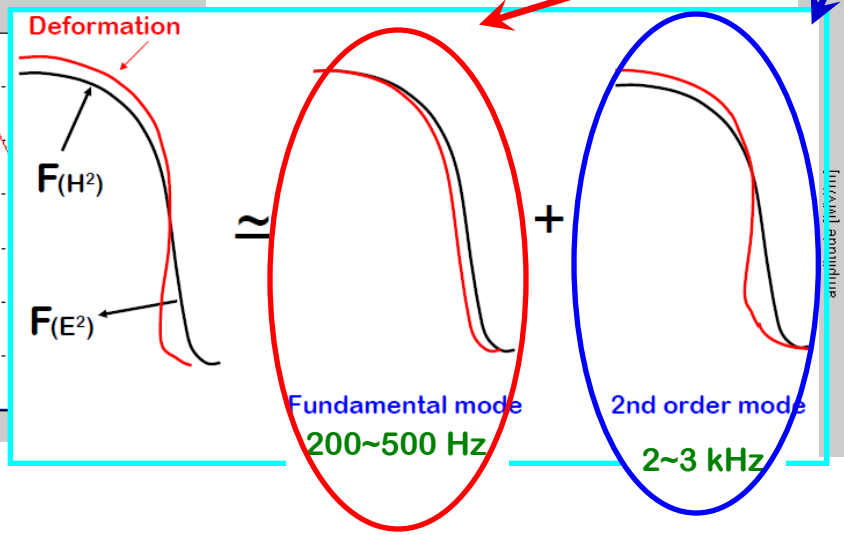




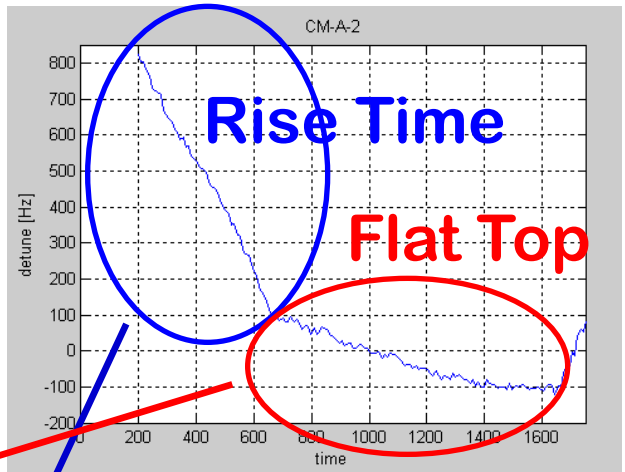
FB/on, Piezo/off

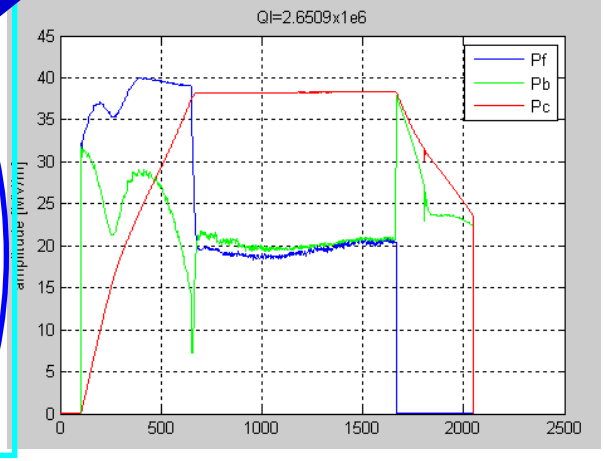
Pre-detuning
by motor tuner
& piezo tuner
with DC voltage

Compensation
by piezo tuner in
pulsed operation



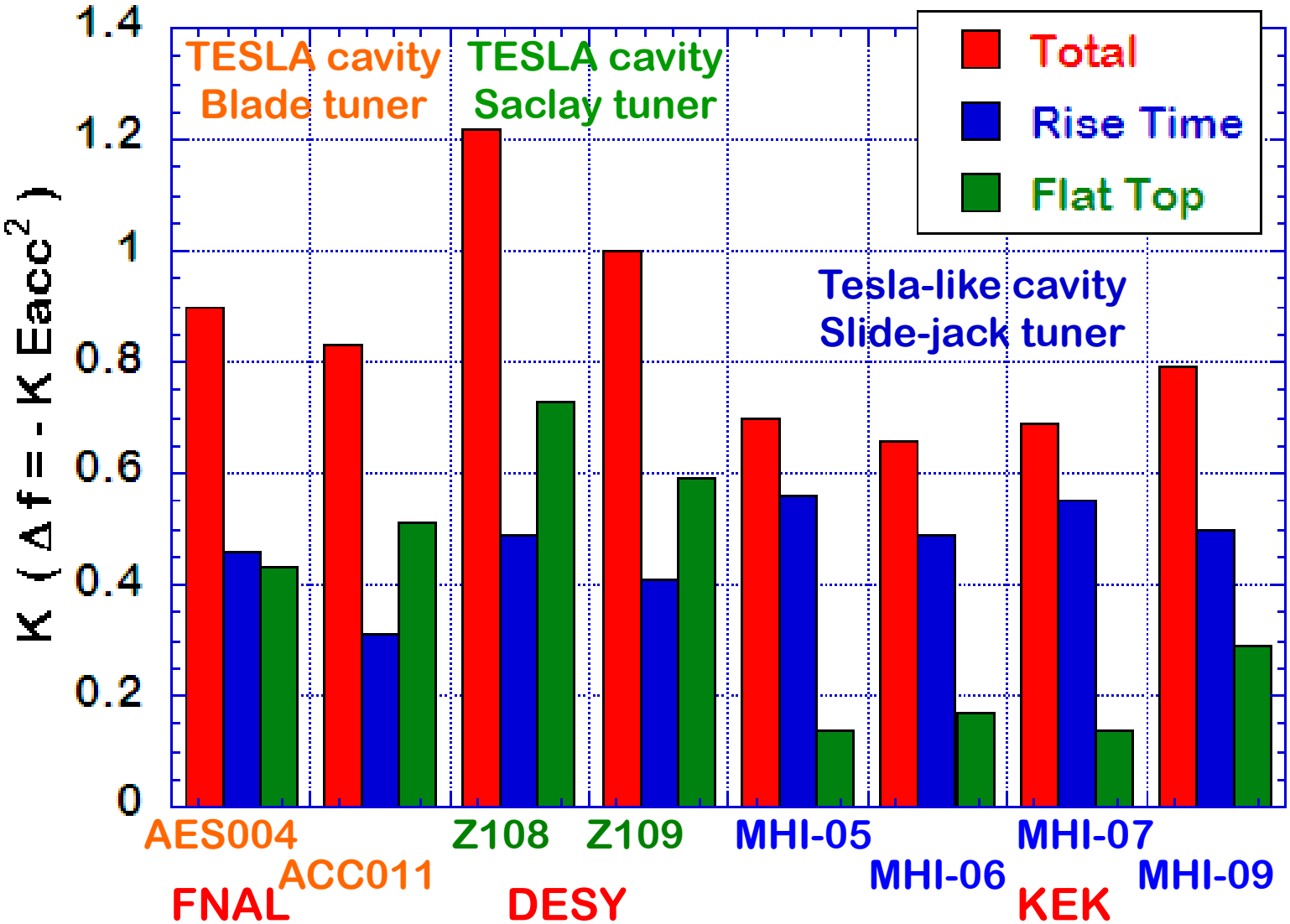
A2/MHI-06 (38MV/m)





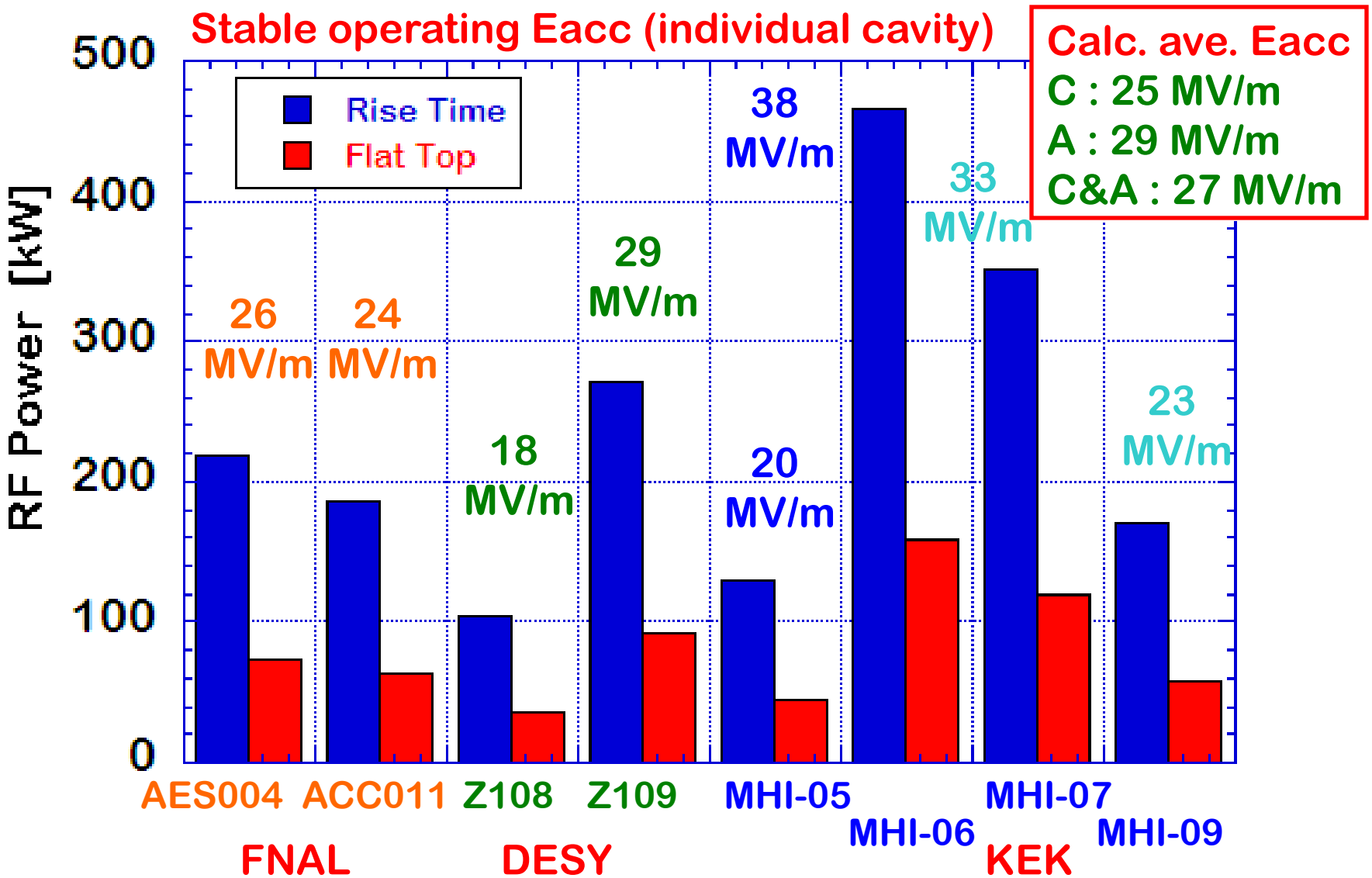
FB/on, Piezo/off

Comparison of Detuning Frequency by LFD



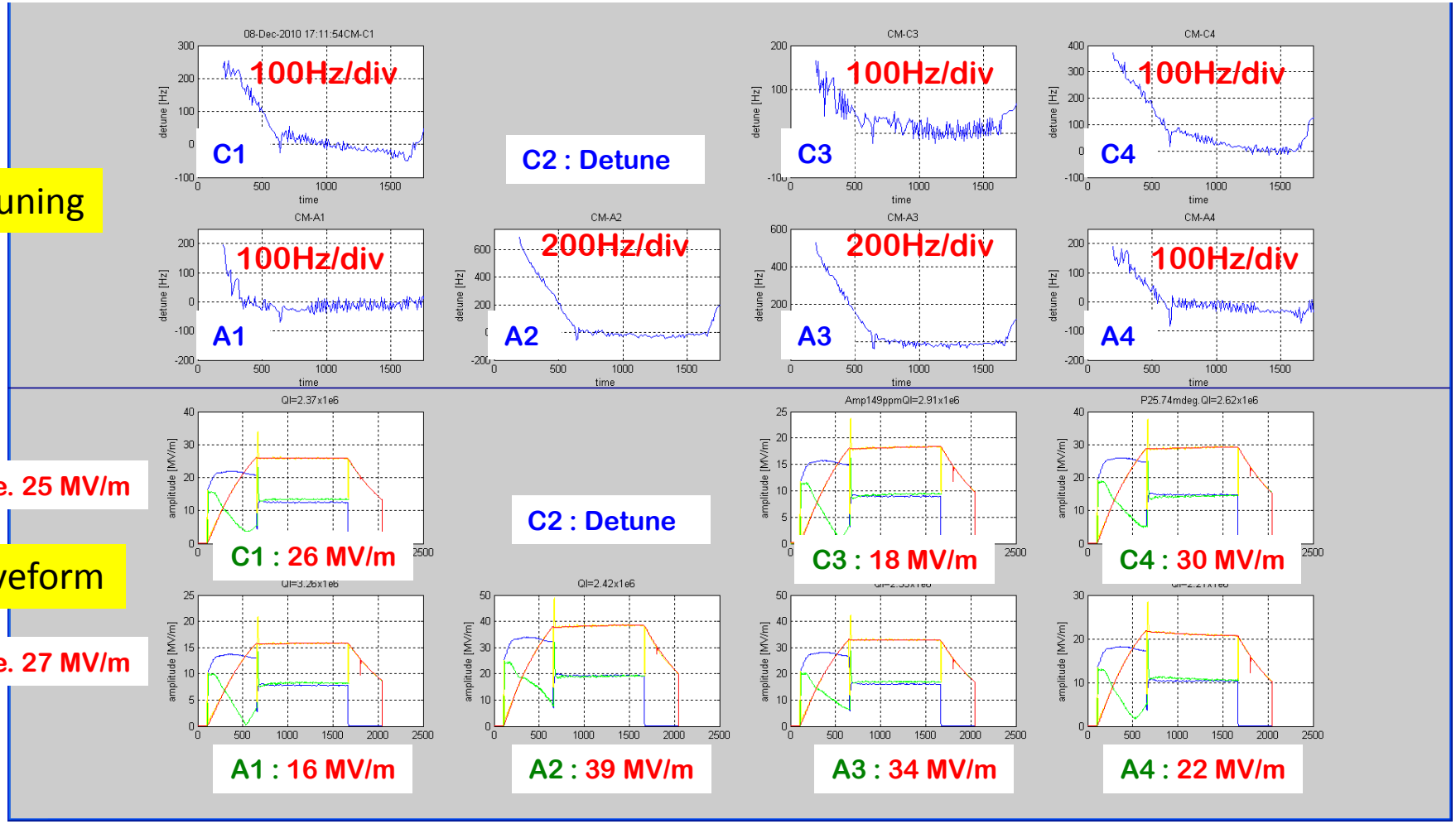
Stiff tuners have small LFD at flat-top.

Required rf power for 8-cav. operation



7-cavity operation in Cryomodule-C&A

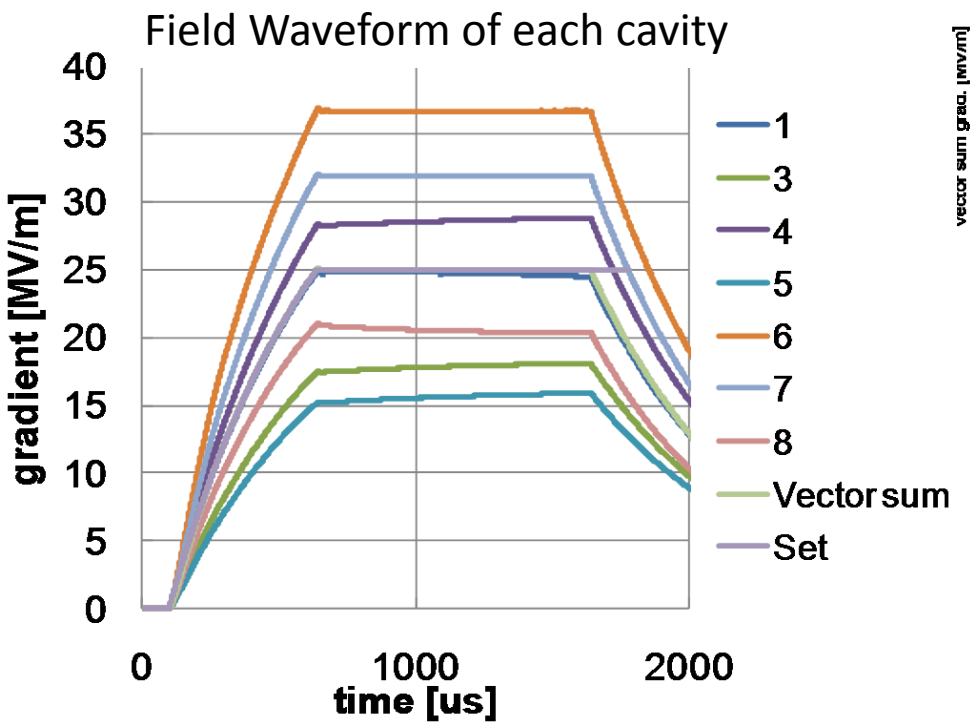
Ave. Eacc = 26.2 MV/m ; FB/on, Piezo/on, 1299.900 MHz

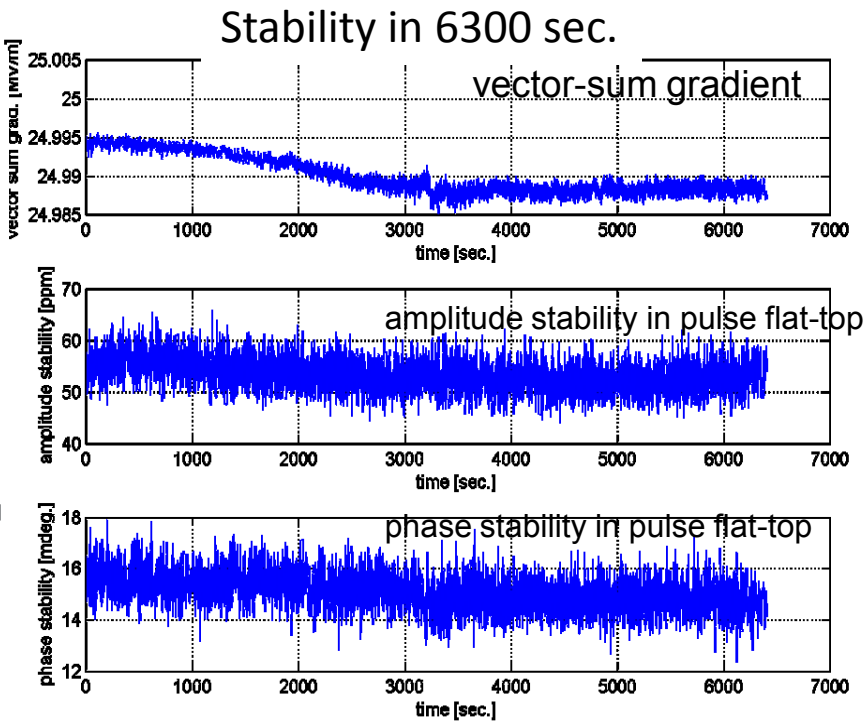


Variation are in detuning waveform shapes.
Cavity field waveform are almost aligned.

7-cavity operation by digital LLRF

LLRF stability study with 7 cavities operation at 25MV/m



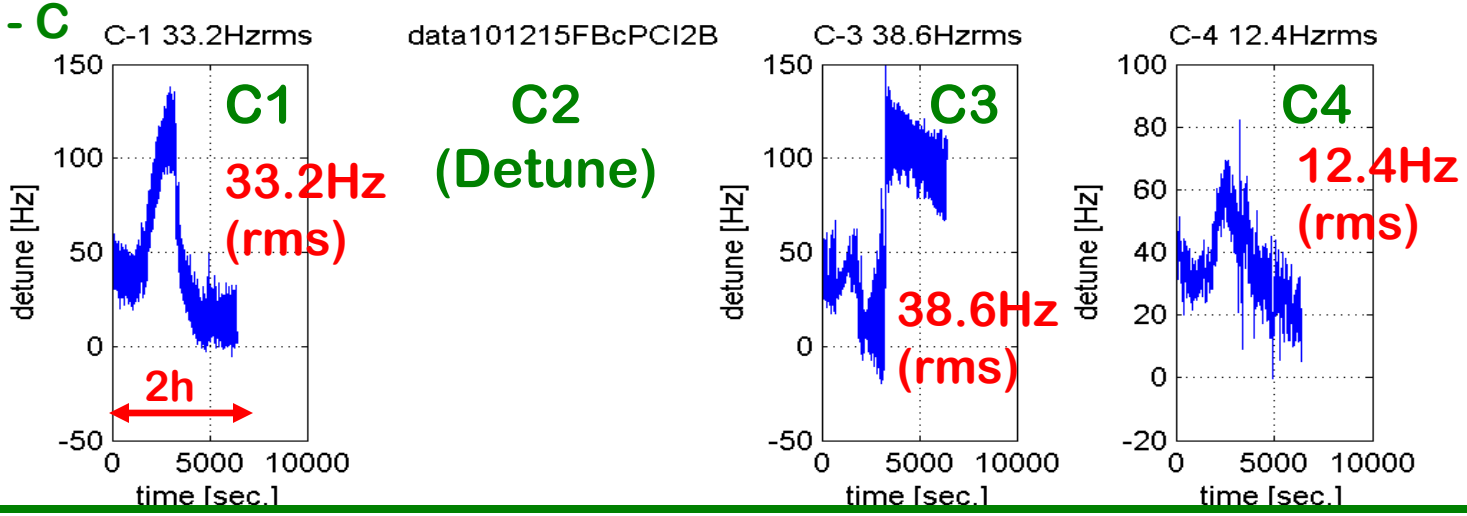


Vector-sum stability: 24.995MV/m ~ 24.988MV/m (~0.03%)
amplitude stability in pulse flat-top: < 60ppm=0.006%rms
phase stability in pulse flat-top: < 0.0017 degree.rms

Stability of Detuning Frequency

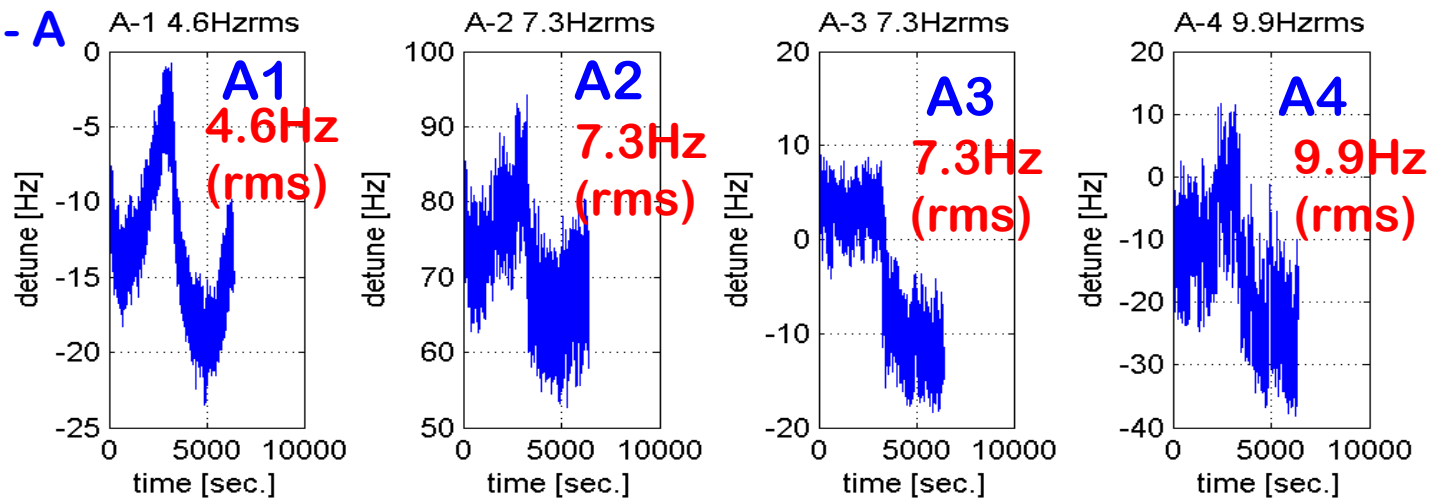
Cryomodule - C

Piezo/on



Cryomodule - A

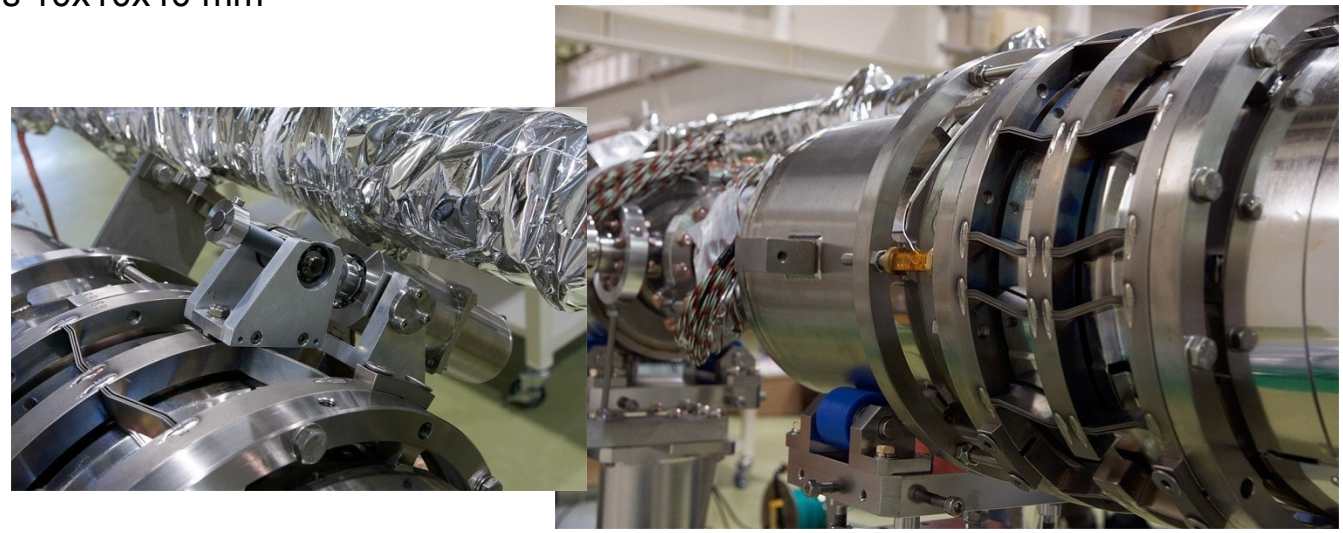
Piezo/on



Detuning frequency stability during 6300seconds;
are 10 - 40 Hz. Sudden change was observed, maybe due to He pressure change.

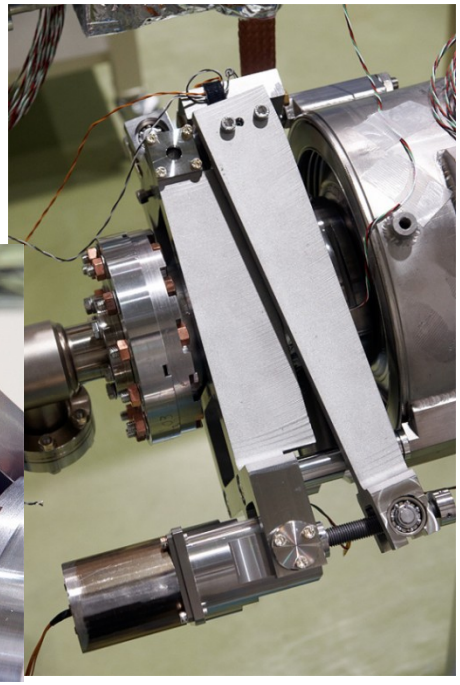
Tuning systems in details: **FNAL/INFN cavity units**

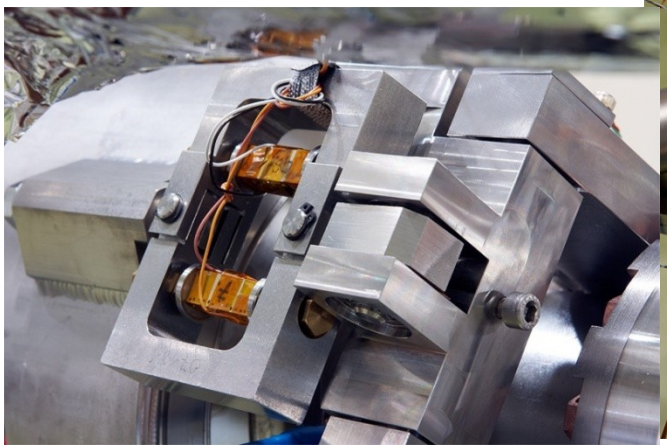
- Blade Tuner rationales:
  - Designed to be as light and as compact as possible
  - Coaxial to the cavity, tuning action in transmitted to cavity through deformation of thin blades to minimize backlash or free play in the system.
  - Piezo action is in series to the tuner one, designed to achieve the highest possible efficiency in transferring the stroke to the cavity
- FNAL/INFN S1-Global cavity units:
  - AES004 (C1) and ACC011 (C2) TESLA cavities
  - Helium tank from FNAL with specific design for coaxial tuner developed for CM2 at ILC-TA
  - Blade Tuner coaxial unit from INFN
  - Phytron stepper motor drive unit and Harmonic Drive gear from FNAL
  - 2 Noliac multilayer low voltage (200 V) piezo actuators, dimensions 10x10x40 mm



Tuning systems in details: **DESY cavity units**

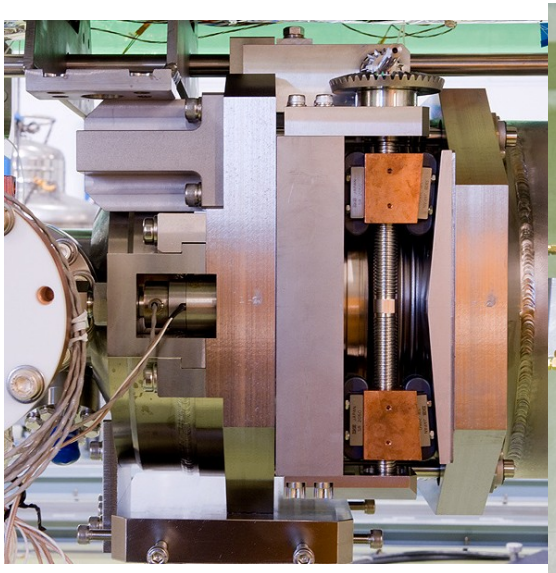
- DESY/Saclay tuner rationales:
  - Affordable and well-known, basically in use since TTF. Originally designed at Saclay an then developed at DESY.
  - Installed at the cavity side opposite to coupler, tuning action is transferred to cavity through a compact double leverage system.
  - Piezo are installed in a preloading frame on one side, their action is transferred through the leverage mechanics.
- DESY S1-Global cavity units:
  - Z108 (C3) and Z109 (C4) TESLA cavities, with standard DESY/FLASH helium tank
  - Lateral DESY/Saclay tuner, latest XFEL-like model
  - Phytron stepper motor drive unit and Harmonic Drive gear from DESY
  - 2 Noliac low voltage (200 V) multilayer actuators

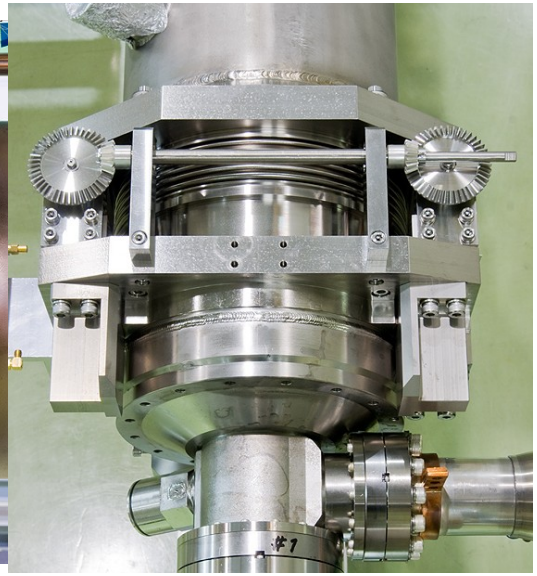




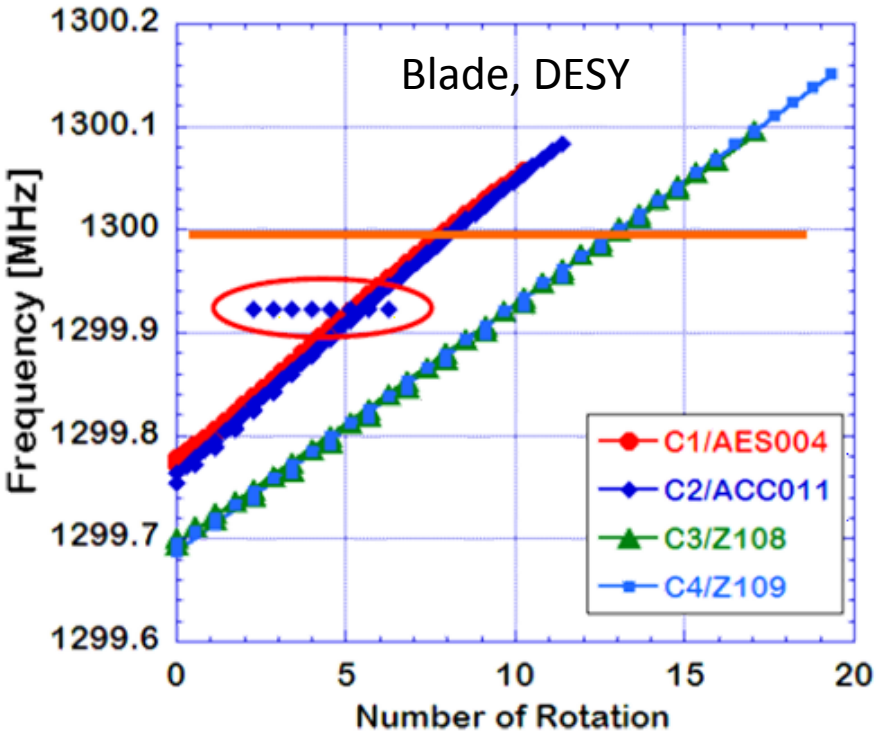
Tuning systems in details: **KEK cavity units**

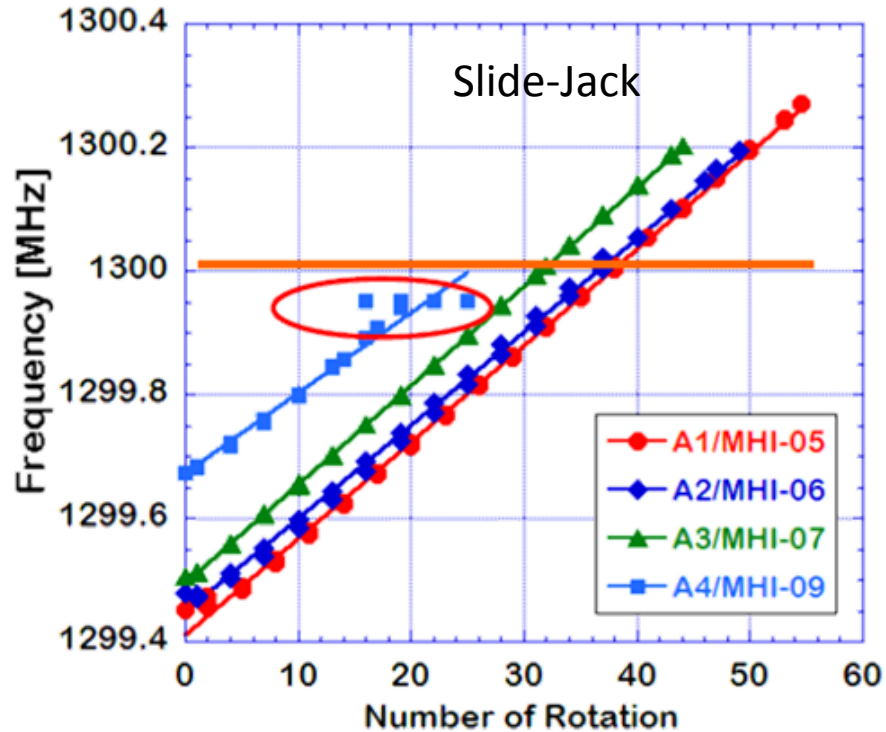
- KEK Slide-Jack Tuner rationales:
  - Stiff design specifically developed for KEK TESLA-like cavities
  - The tuning driving action is generated outside the vessel and transferred to a feed-trough shaft: no motor units is required to be install inside the module.
  - The longitudinal strain is generated through rolling elements sliding on a sloping surface
  - One single piezo acts in series to the tuner and is installed on the fixed side
- KEK S1-Global cavity units:
  - KEK TESLA-like cavities: MHI05 (A1), MHI06 (A2), MHI07 (A3) and MHI09 (A4)
  - For A1 and A2, helium tank with bellow between pads and Slide-Jack Tuner installed as middle tuner
  - For A3 and A4, helium tank with bellow at coupler side and Slide-Jack Tuner installed as lateral tuner outside pads.
  - Tuner is driven by a stepping motor drive unit through a drive shaft.
  - One high voltage (1000 V limited to 500 V), few-layer piezo stack from PiezoMechanik. Dimensions: 35 mm diameter and 50 mm length.





Static tuning range at cold (Mechanical Tuner)

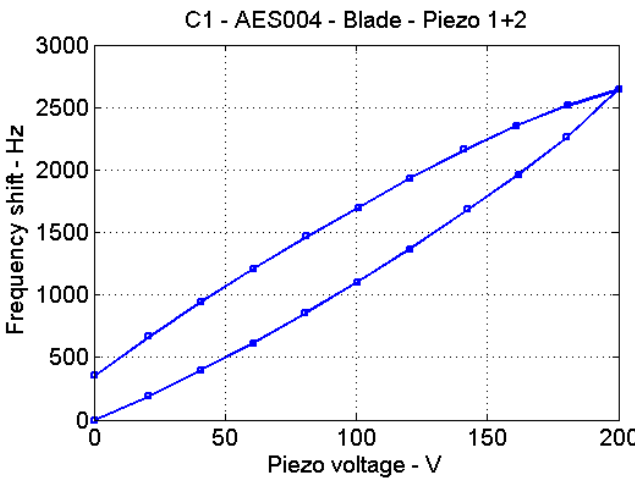


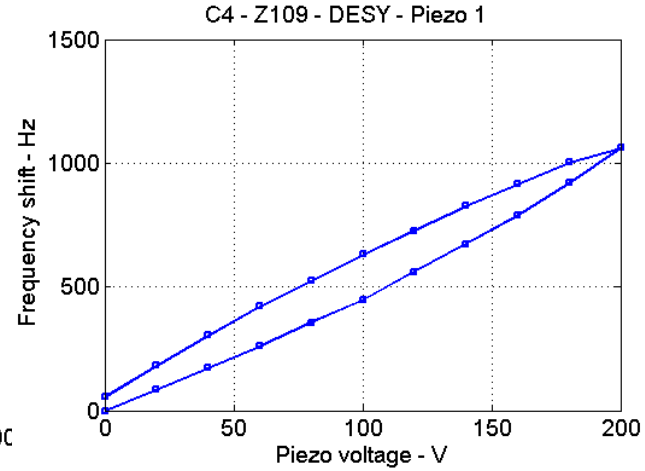


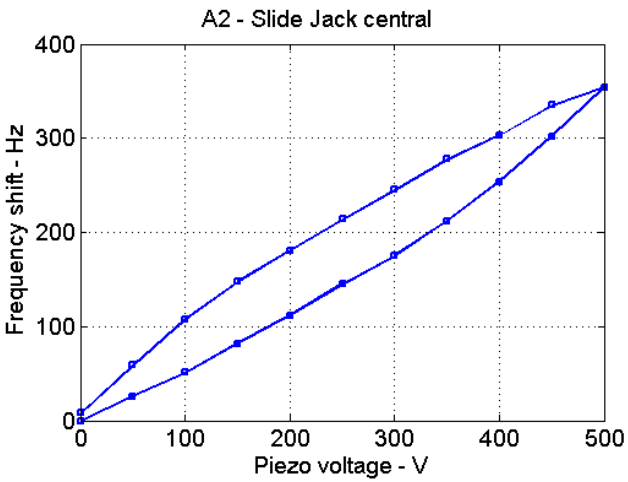
	Blade Tuner (C2)	DESY tuner (C4)	Slide-Jack tuner (A1)
Coarse tuning range measured (expected value)	330 kHz 12/22 turns (600 kHz)	450 kHz 19/23 turns (500 kHz)	800 kHz 54/60 turns (900 kHz)
Tuning sensitivity at 1.3 GHz (expected value)	25 kHz/spindle turn	20 kHz/spindle turn	15 kHz/spindle turn
	1.4 Hz/step (1.5 Hz/step)	1.1 Hz/step (1 Hz/step)	3 Hz/step (3 Hz/step)

- Issue with Blade Tuner in cavity C2:
  - during the second cycle the frequency resulted to be stacked at 1299.92 MHz.
- Issue with Slide-Jack Tuner in A4:
  - Failure in the driving shaft joint and frequency stacked at 1299.95 MHz.
- Under investigation …

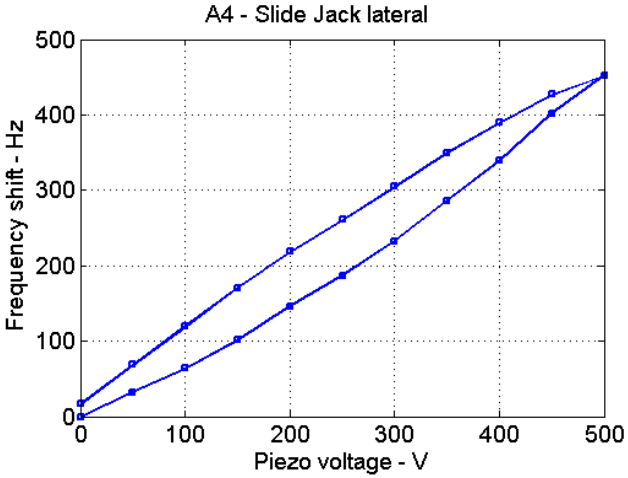
Selection of piezo DC response curves (Piezo Tuner)





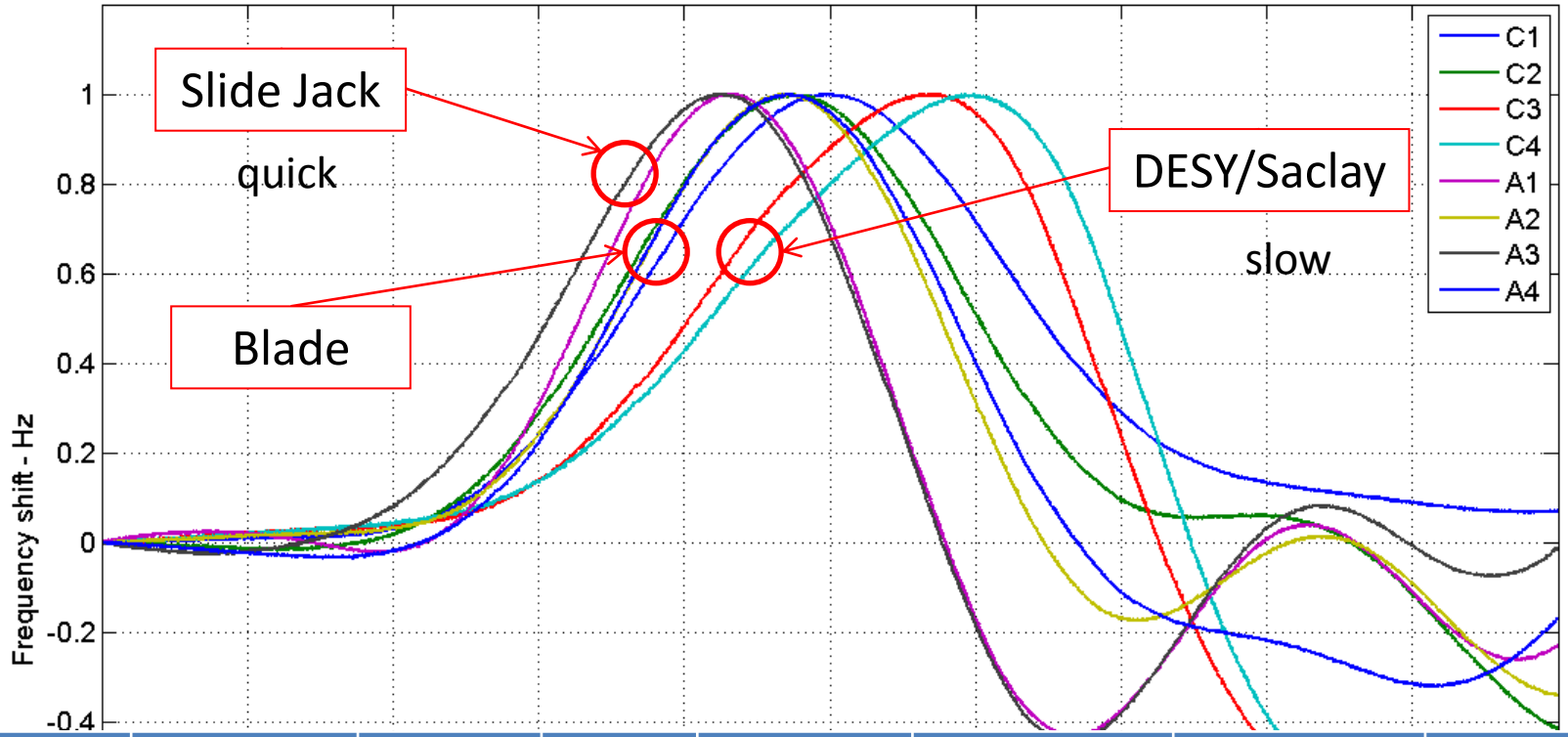


Cavity	Maximum nominal piezo voltage [V]	Piezo configuration	Maximum applied voltage [V]	Frequency shift [Hz]
C1-Blade	200	1+2	200	2650
C2-Blade	200	1	200	610
C3-DESY	200	2	200	1010
C4-DESY	200	1	200	1060
A1-S.J cent.	1000	-	500	190
A2-S.J cent.	1000	-	500	350
A3-S.J lat.	1000	-	500	210
A4-S.J lat.	1000	-	500	450



One of piezo in C2 has discharge trip problem.

Piezo sine-wave pulse response (Piezo Tuner)



Cavity-Tuner	Max. piezo voltage [V]	Load C at 2 K [µF]	Piezo Config.	SIN pulse amp. [V]	Max. Freq. shift in 1 ms [Hz]	Best lead from pulse start [ms]	Dyn. over Static detuning ratio
C1-Blade	200	4.1	1+2	135	1040	1.31	0.6
C2-Blade	200	3.9	1+2	100	590	1.24	1
C3-DESY	200	2.0	2	180	1100	1.58	1.2
C4-DESY	200	1.9	1	170	1170	1.64	1.3
A1-S.J cent.	1000	0.19	-	470	270	1.10	1.5
A2-S.J cent.	1000	0.21	-	470	450	1.26	1.4
A3-S.J lat.	1000	0.20	-	470	270	1.03	1.3
A4-S.J lat.	1000	0.21	-	470	450	1.22	1.1

Comments on low power CW tests

- Piezo issues in C2:
  - Severe lack of mechanical coupling on both piezo
  - Piezo 2 discharging at lower voltage, not seen at RT.
  - Puzzling scenario: possibly correlated to static tuning failure? To be investigated.
- Assuming DESY design as a reference, the other two rely on different design concepts:
  - "*Small external stiffness guideline*" for the Blade Tuner:
    - Simple and light cavity constraints (i.e. end cones), and therefore the same for the tuner
    - achieve a large LFD compensation capability as required
  - "*High external stiffness guideline*" for the Slide-Jack Tuner:
    - Strong and stiff cavity constraints, and therefore the same for the tuner
    - Minimize the amount of LFD to be compensated
- Collected data set is fully consistent with the scenario previously described:
  - "Soft" Blade (and DESY actually) units systems act as low-bandwidth systems, with dominant modes placed at lower frequency and therefore longer rise-time.
  - "Stiff" KEK units act as high-bandwidth systems, with dominant modes at higher frequency and shorter rise-time.
  - Very large DC stroke for the Blade Tuner piezo system (C1). This does not lead to equivalently high dynamic tuning capabilities. Lower static-to-dynamic detuning ratio is due to the very small overshooting.

Study of circulator removal for cost reduction

RF distribution at DRFS

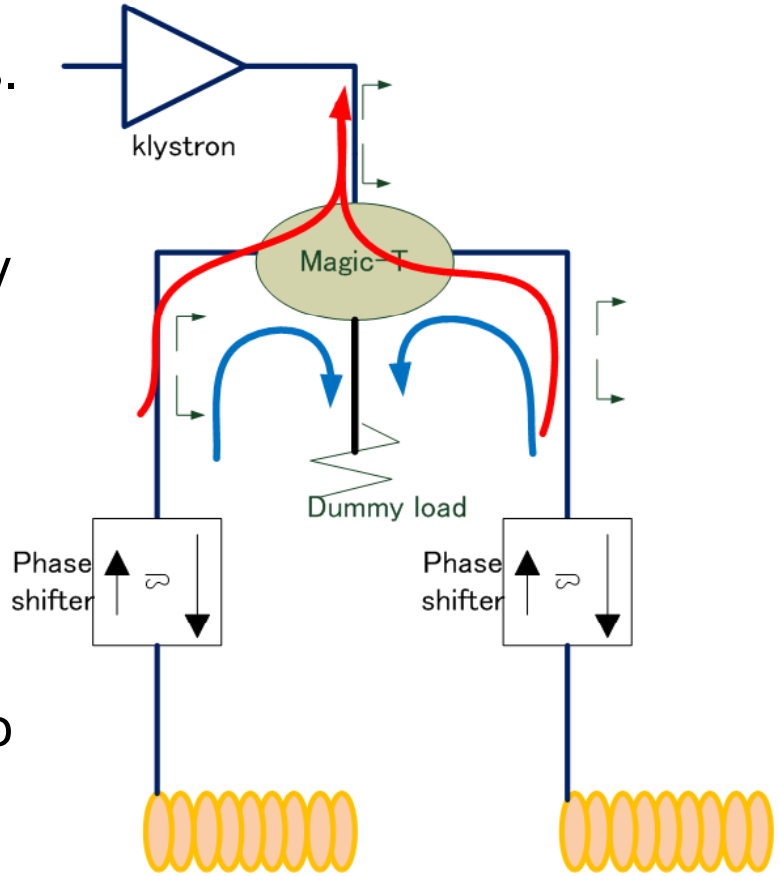
- One klystron drives two cavities.
- Circulator-less system.

Same (amplitude and phase) reflection signals go to the dummy load.(blue line)

- Un-balanced reflection signals move to the klystron. (red line)

-> careful operation is required to protect the klystron.

- Phase-shifters are introduced to evaluate the system. (not to be used at ilc-DRFS)

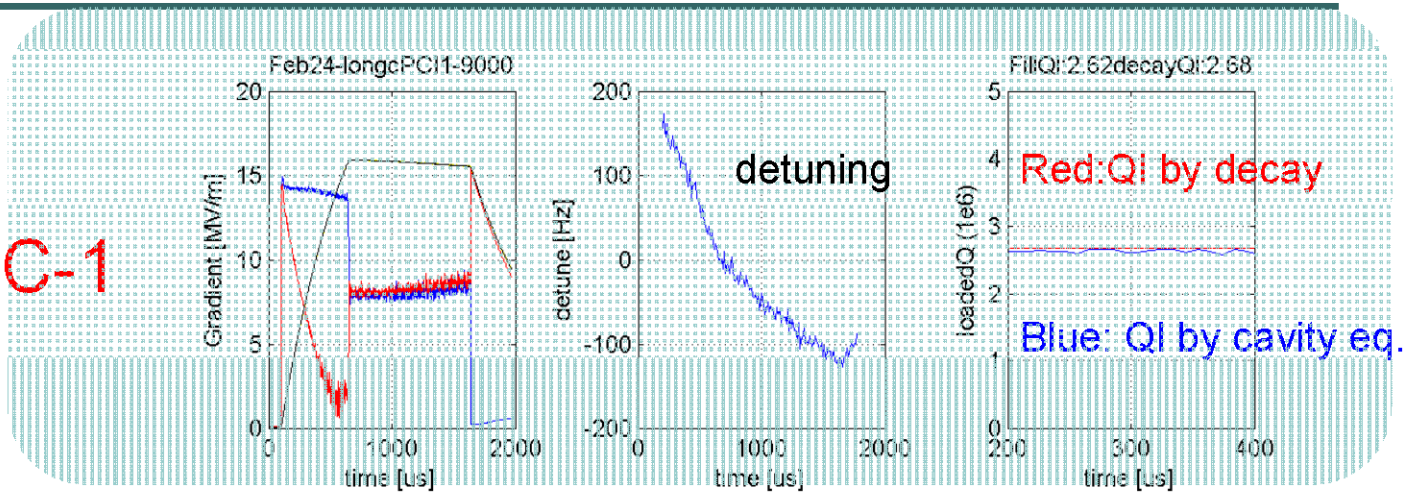


S1G meeting (Mar.08,2011)

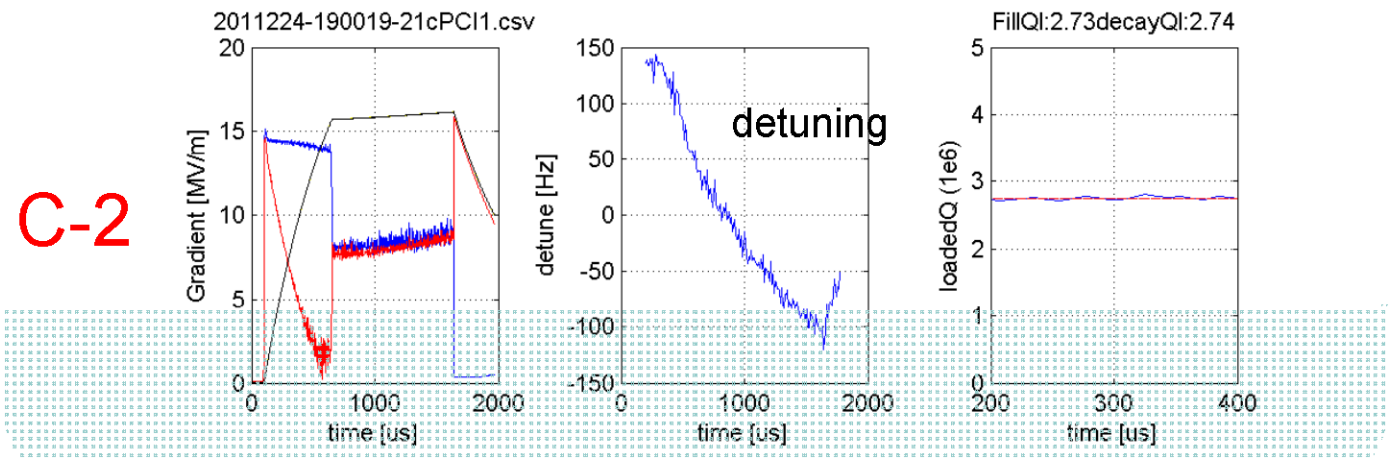
Study of circulator removal for cost reduction

Detuning and Ql under typical operation

Cav. C-1



Cav. C-2



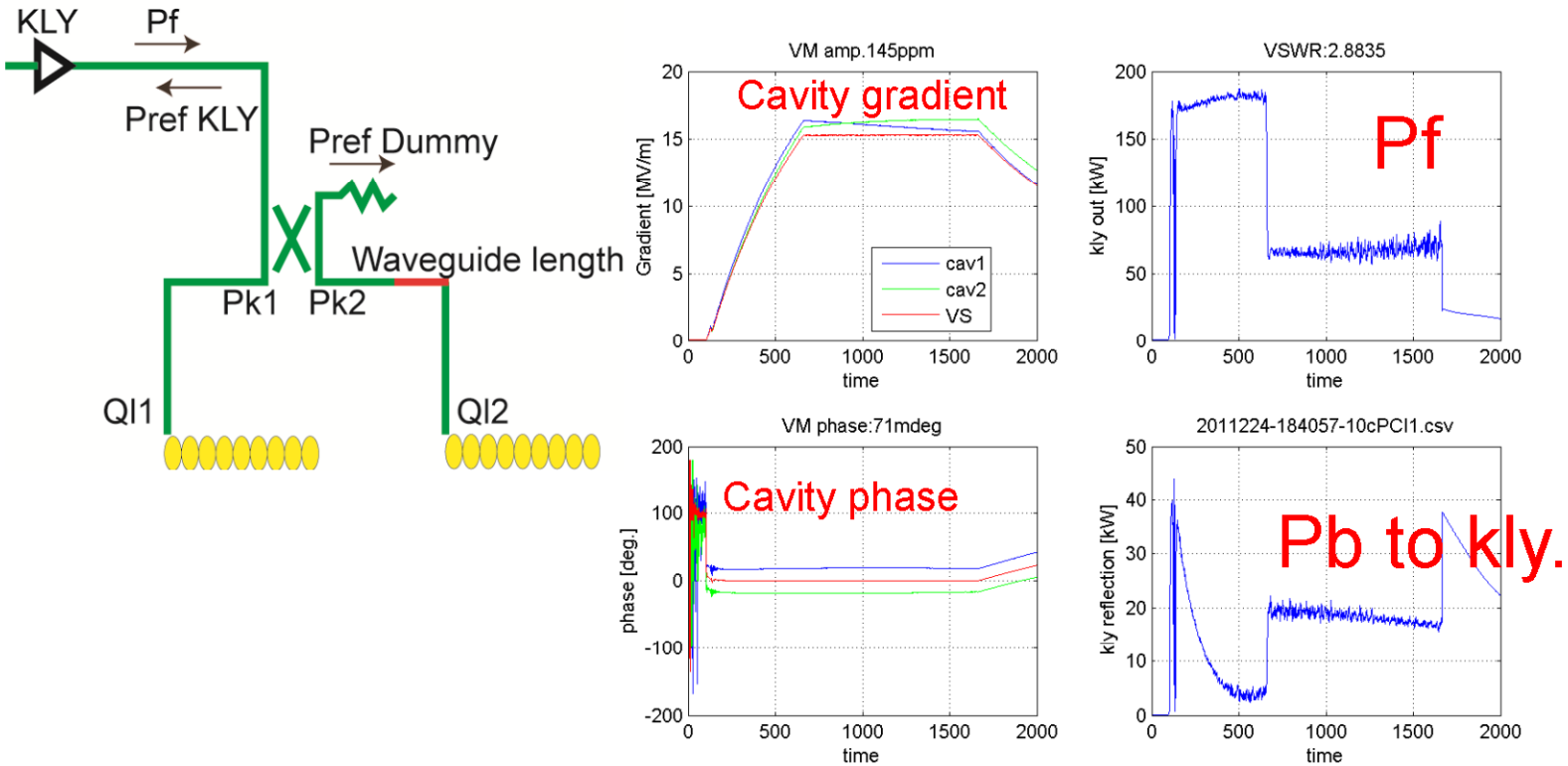
- Loaded Qs calculated simple time decay are correct at this case.

S1G meeting (Mar.08,2011)

03082011 S1-G webex: S. Michizono

Studv of circulator removal for cost reduction

Un-matched operation with VS control



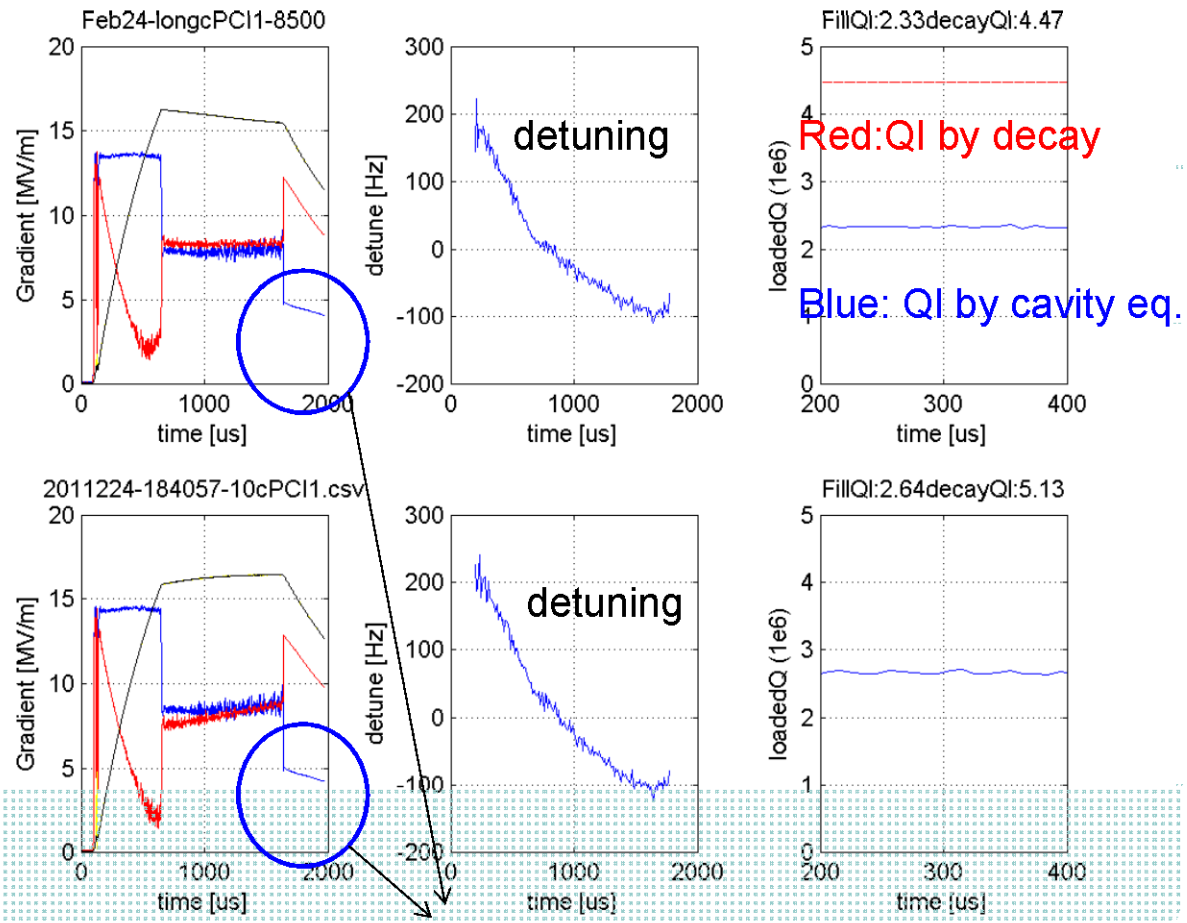
- Reflection to the klystron is ~20kW (max VSWR=2.8)
- Vector sum is still regulated. (amplitude: 0.015%rms, phase:0.07deg.rms)

S1G meeting (Mar.08,2011)

Un-matched operation (detuning and Ql)

Cav. C-1

Cav. C-2



Crosstalk between cavities

- Ql by decay: ~4e6 -> This is not correct.
- Ql by cavity equation: ~2.5e6

S1G meeting (Mar.08,2011)

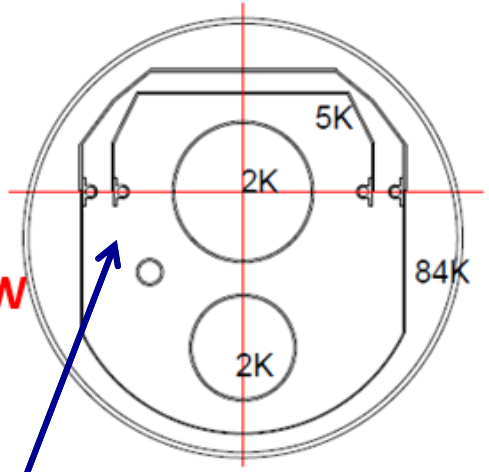
Study of 5K shield removal for cost reduction

Module-B cold test

(June-Sept2009)

- Object of the Module-B cold test
  - Measuring heat loads at 2K dummy cavity vessels with and without 5 K shield lower parts.
    - Heat load was measured by the evaporated 2K liquid helium in 4 dummy vessels.
  - Measuring heat loads at 5K and 80K shields.
    - Heat loads at 5K and 80K were measured by the temperature rise of each thermal shield.
  - Estimating heat load and emissivity of cryomodule components at each temperature.
    - Calculation was performed by ANSYS.
- Measured heat loads at 2K dummy cavity vessels with and without 5 K shield lower parts.
  - Difference of the heat input between two cases = **0.79 W**

ANSYS calculation results 0.76W, consistent with measurement



Calculation model

5K shield removal

Study of 5K shield removal for cost reduction

ILC cryogenic system

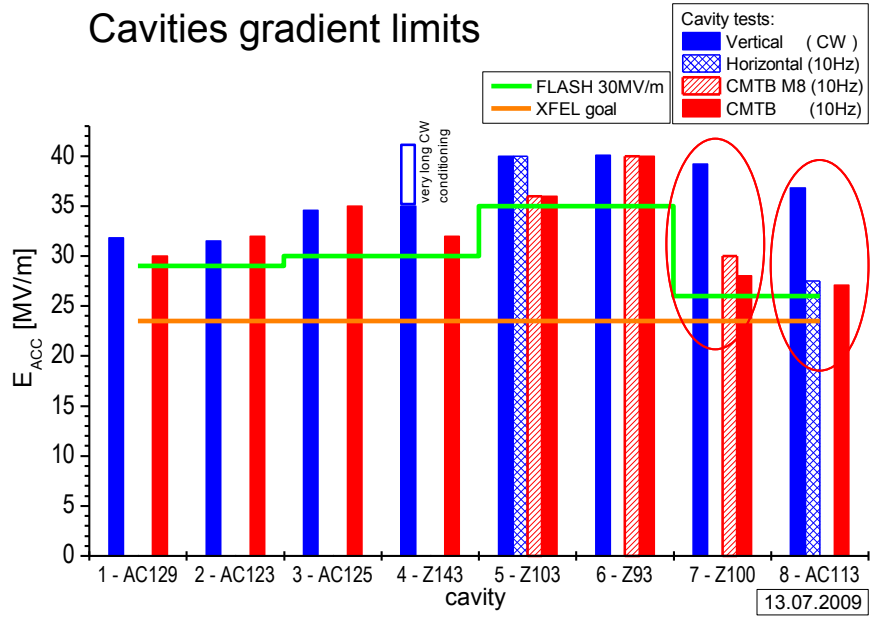
46K shield, 5K shield

- One refrigerator
  - Cooling 192 modules along 2.47 km
  - Designed cooling power = 25 kW at 4.5 K
- At 2 K level of module components
  - By thermal radiation for one module (9 cavities):
    - With 5 K shield, $Q_{2K} = 3.8 \times 10^{-4} \times (9/4) = 0.0009$ W
    - Without 5 K lower shield and 46K outer shield, $Q_{2K} = 0.047 \times (9/4) = 0.11$ W
  - For one cryogenic unuit:
    - Difference between 5K full shield and 5K upper shield = 0.11 W×192 modules = 21.1 W at 2 K (corresponding to 52.8 W at 4.5 K).

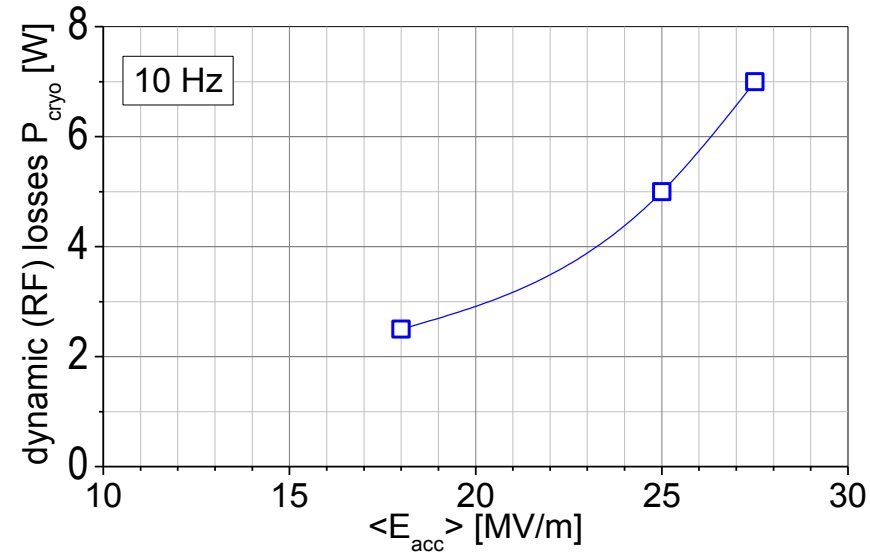
DESY PXFEL cryomodule test

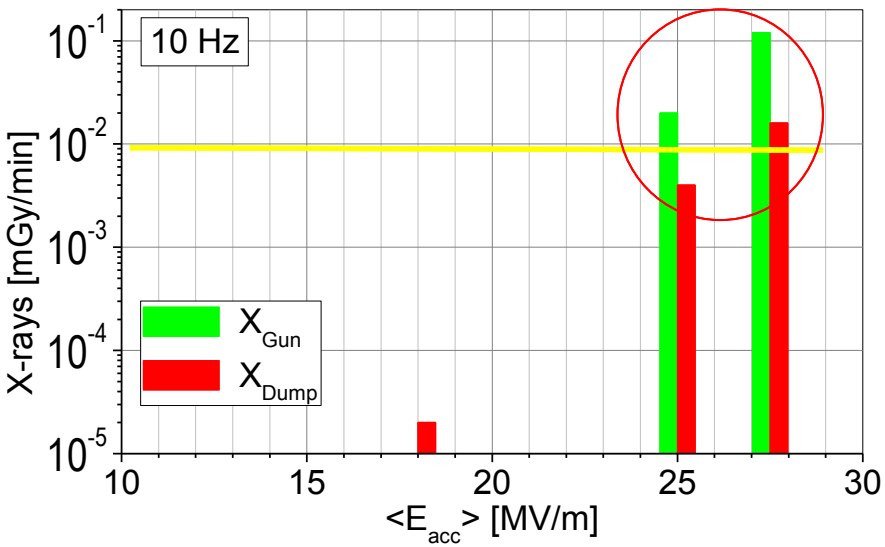
Cryo Module Test Bench

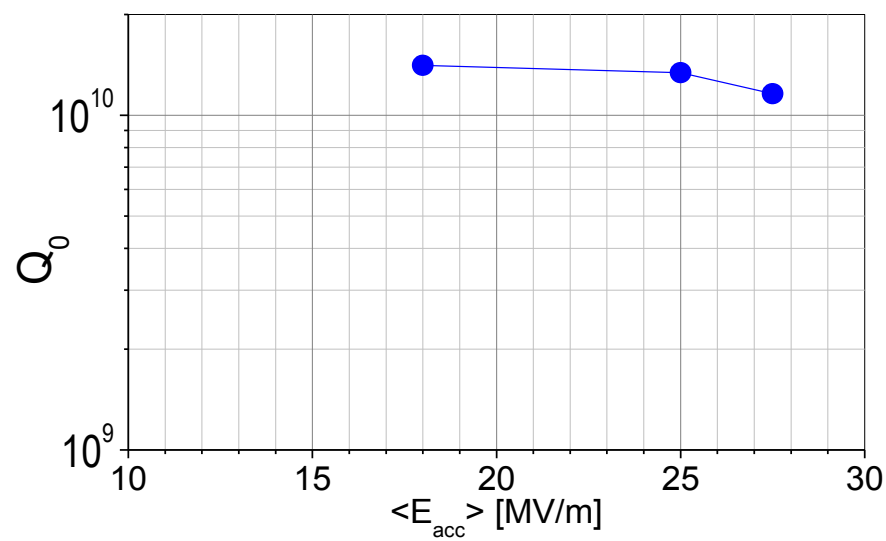
Module Test Results: PXFEL1



PXFEL1 module was installed in the FLASH linac.

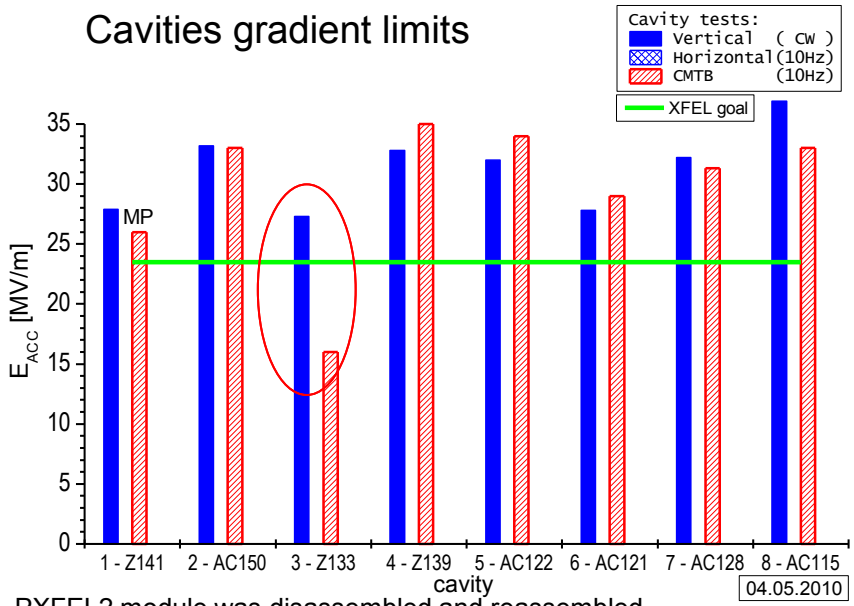




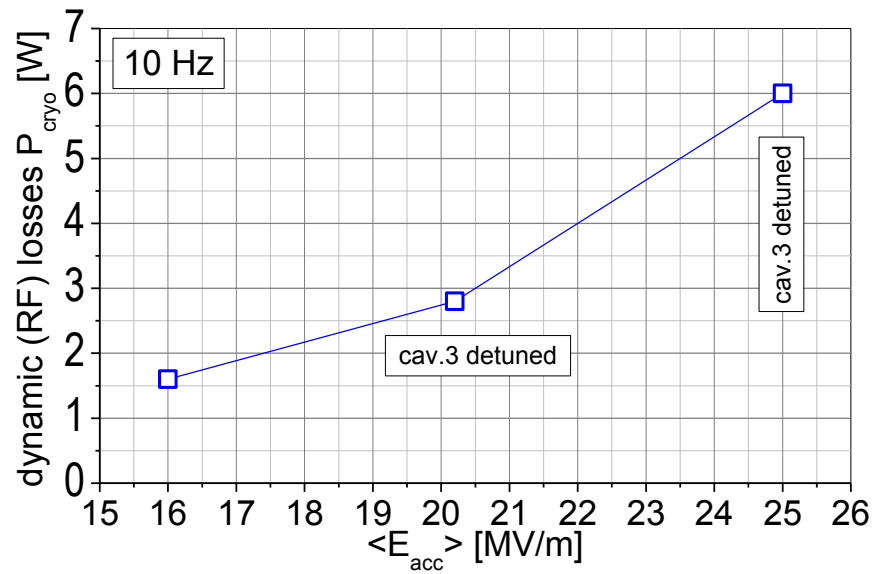


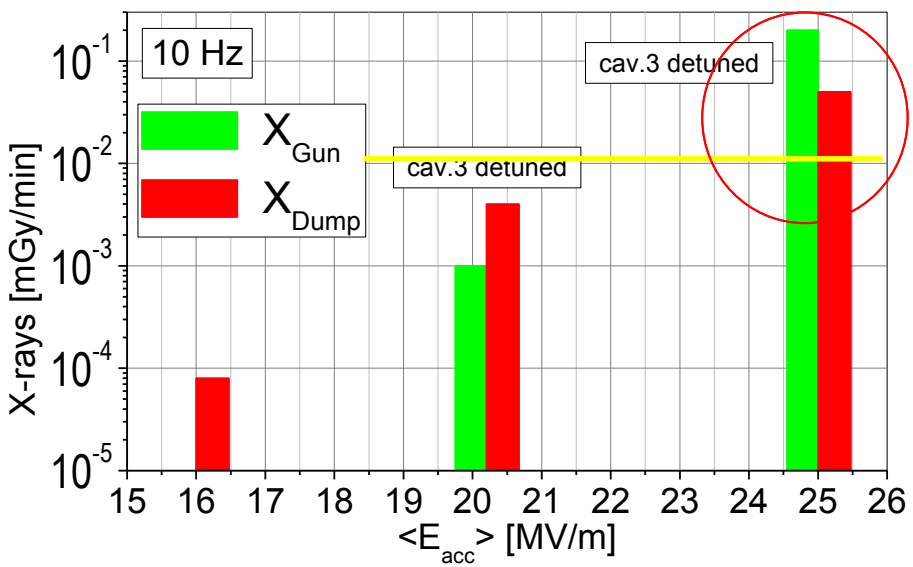
10^{-2} mGy/min = 10 µSv/min = 600 µSv/h for X-ray

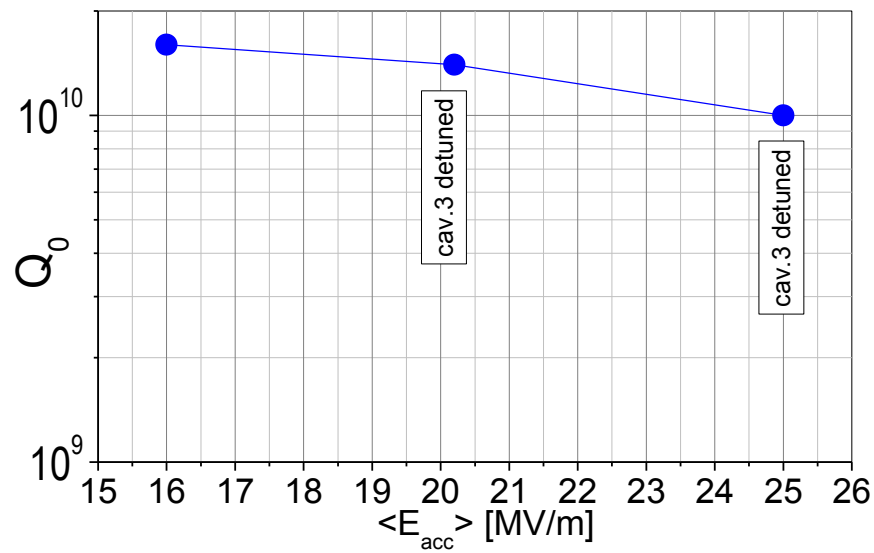
Module Test Results: PXFEL2



PXFEL2 module was disassembled and reassembled.

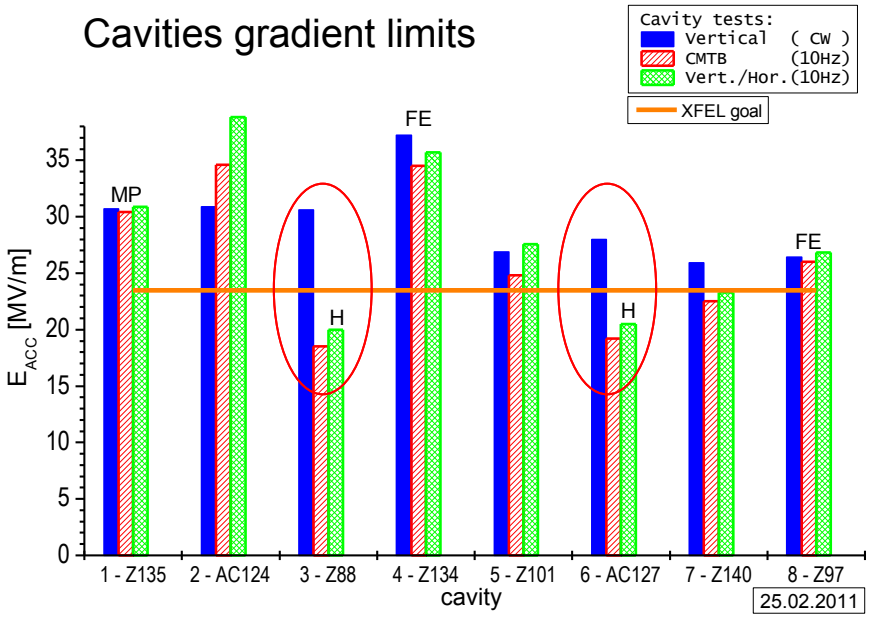


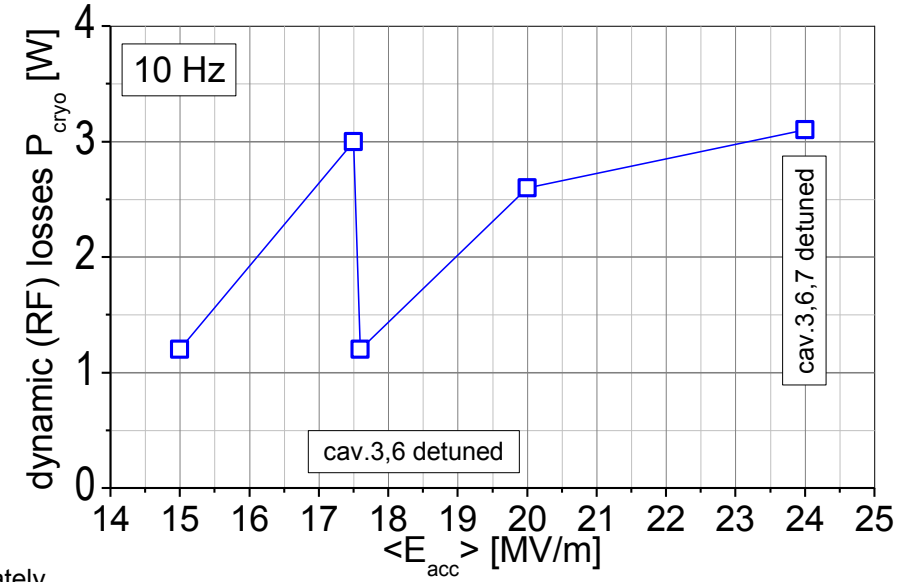




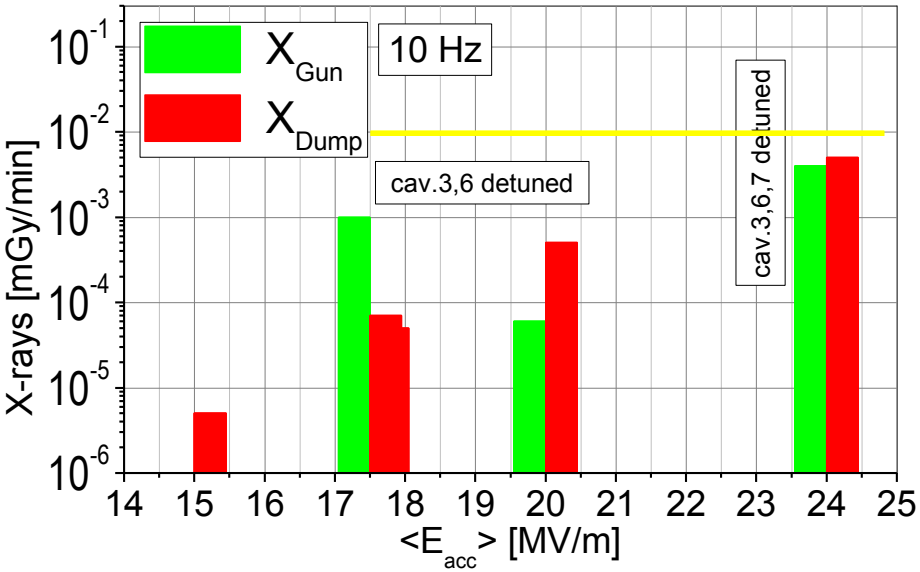
10^{-2} mGy/min = 10 µSv/min = 600 µSv/h for X-ray

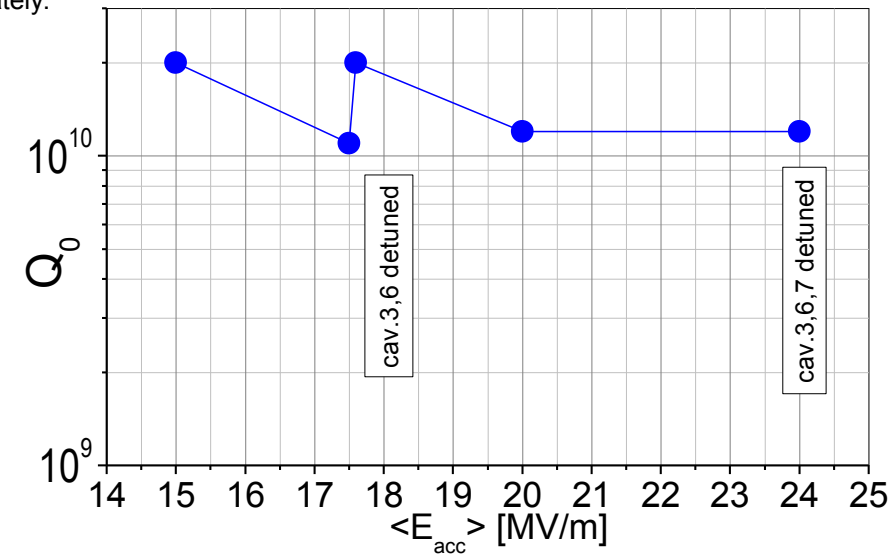
Module Test Results: PXFEL3





PXFEL3 module was disassembled, cavities are currently being tested separately.





cavities 3 and 6 have high cryo-losses, in the horizontal test after disassembly both cavities have high cryo-losses.

10^{-2} mGy/min = 10 µSv/min = 600 µSv/h for X-ray

FNAL CM1, CM2 cryomodule test

CM-1 Team at Fermilab

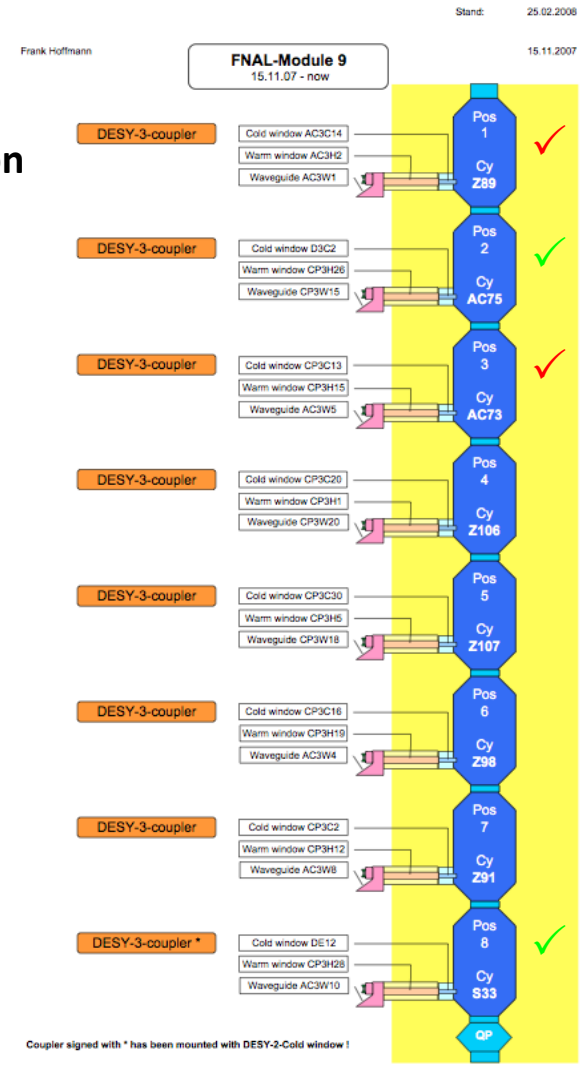
CM1 Milestones:

- **Jan. 2010: installation in NML tunnel**
- **Aug. – Oct. 2010: warm coupler conditioning**
- **Nov. 2010: Cool down to 2K**
- **Feb. 2011: Start powering each cavity**

E. Harms

CM-1 Status, as of 19 Apr 2011

- **Cavity #1 (Z89) assessment complete**
  - **Reached gradient: 23-24MV/m**
  - **LLRF operation and LFD compensation demonstration**
  - **Large heat load: yet to be understood**
- **Cavity #8 (S33) assessment complete**
  - **Reached gradient: 23.4MV/m**
  - **stuck tuner motor: yet to be understood**
- **Cavity #2 (AC75) assessment complete**
  - **Reached gradient: 26MV/m**
- **Cavity #3 (AC73) assessment complete**
  - **Reached gradient: 17MV/m**
- **Cavity #4 (Z106) powered testing to begin this week**



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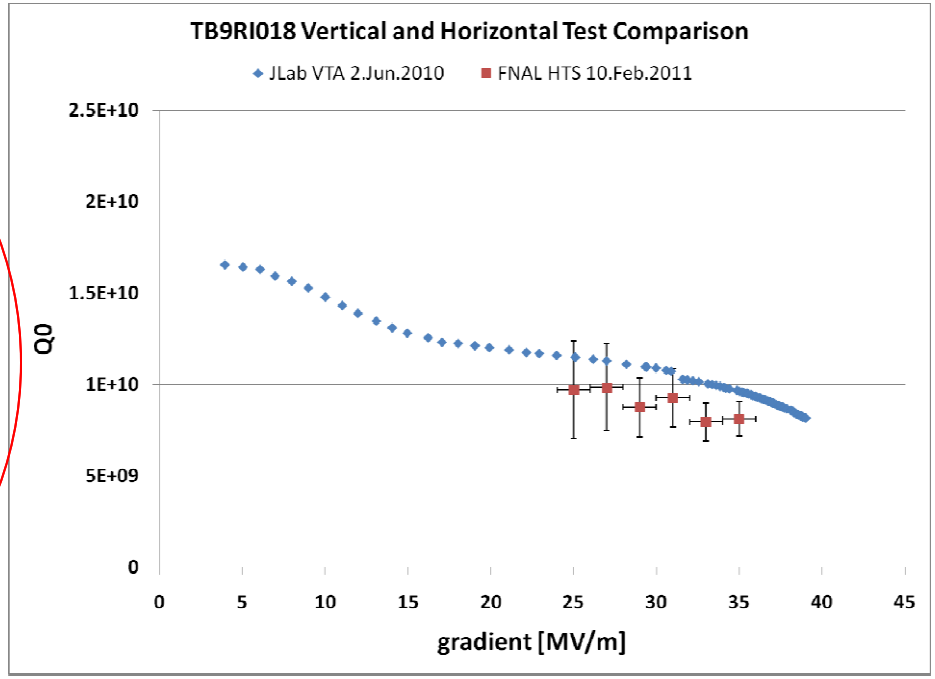

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High performance cavities are ready for FNAL CM-2

Conclusion from these tests

S1-G Test

(1) Average cavity performance: 30MV/m in VT, 27MV/m each process, 26MV/m 7-cav. Combined.

(2) Two cavities degraded, One coupler degraded, Two tuner did not work. One piezo discharge problem.

(3) Coupler performance were similar, however, KEK coupler has large heat load.

(4) All 4 kind of tuner were worked, with different LFD response.

(5) X-ray emission are little bit high.

Circulator removal study

(1) Operation confirmed in two cavities system with magic-T.

(2) New method for QL monitoring were required.

5K shield removal study

(1) Increased heat load to 4.5K will be only 52.8W for 25kW cryogenic system.

DESY PXFEL cryomodule Test

(1) Cavity performance of three cryomodules are well above XFEL spec.

(2) 1-2 cavities are degraded in each cryomodule.

(3) X-ray emission are little bit high.

FNAL CM-1 cryomodule Test, preparation of CM-2

(1) Performance test of CM-1 is underway. (low Q, tuner motor stuck)

(2) High performance cavities are prepared for CM-2.

Issues to be addressed

(1) Cavity performance degradation in cryomodule.
(2) X-ray emission in cryomodule.
(3) Low Q0 cavity in cryomodule.
(4) Tuner failure (mechanical & Piezo, both)
(5) Coupler vacuum trip

END