Comparison of Tuner Performance in S1-G Cryomodule

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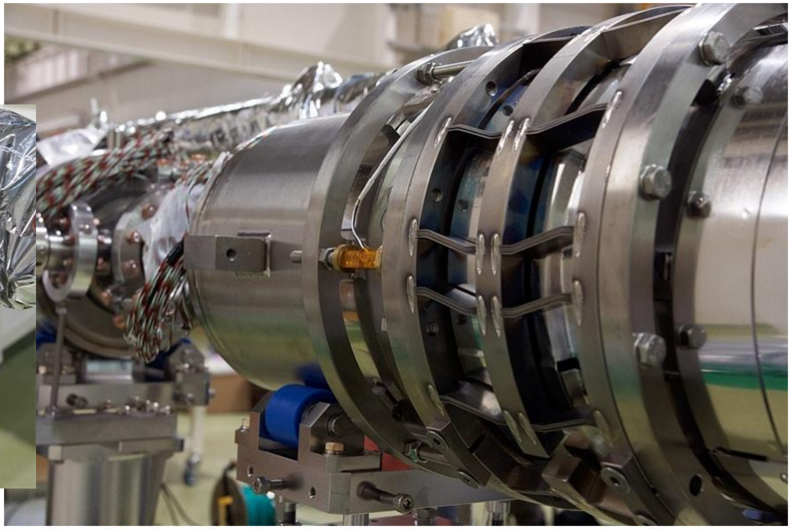
on behalf of S1-Global team

Outline of the talk

- Tuning systems installed in S1-Global:
  - **Rationales and details**
- Low power CW cold tests:
  - **Static tuning capabilities**
  - **Dynamic tuning capabilities**
  - **Spectral analyses**
- Pulsed high power cold test:
  - **Measurement of dynamic LFD**
  - **LFD compensation with FNAL Piezo Control System**
  - **LFD compensation with KEK Piezo Control System**
- Conclusions

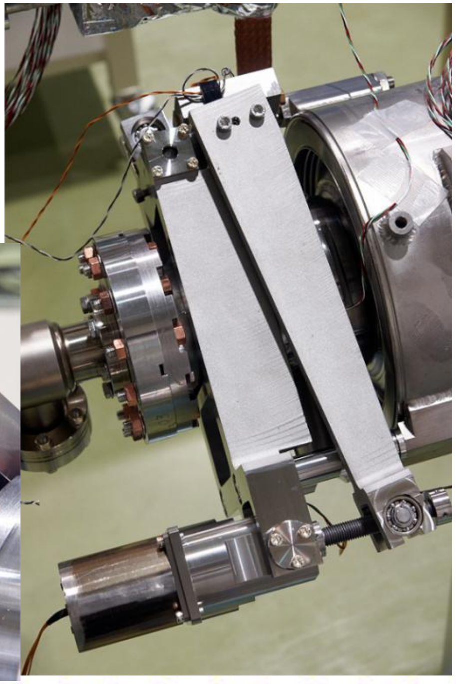
Tuning systems in details: FNAL/INFN cavity units

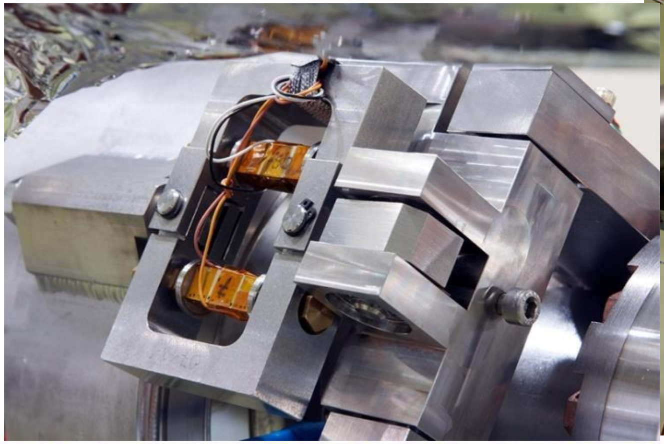
- Blade Tuner rationales:
  - **Designed to be as light and as compact as possible**
  - **Coaxial to the cavity, tuning action in transmitted to cavity through deformation of thin blades to minimize backlash or free play in the system.**
  - **Piezo action is in series to the tuner one, designed to 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

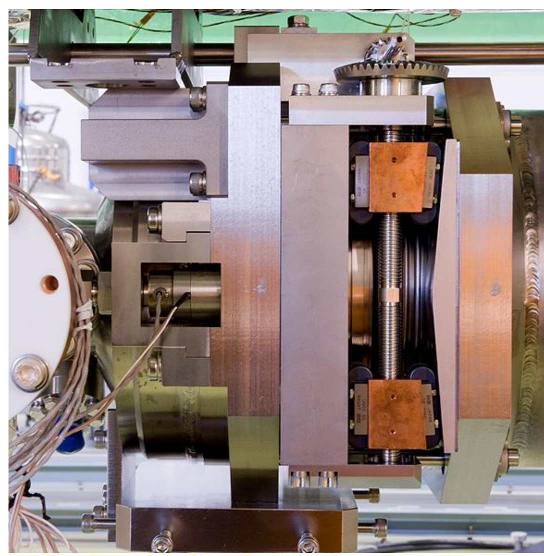
- DESY/Saclay tuner rationales:
  - **Affordable and well-known, basically in use since TTF. Originally designed at Saclay an then developed at DESY.**
  - **Installed at the cavity side opposite to coupler, tuning action is transferred to cavity through a compact double leverage system.**
  - **Piezo 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**

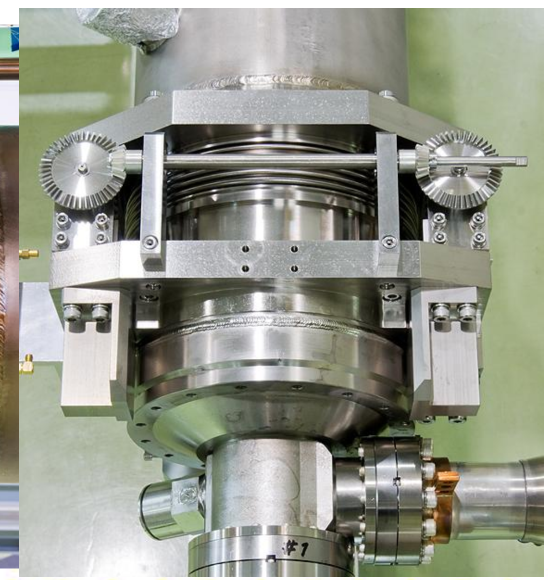




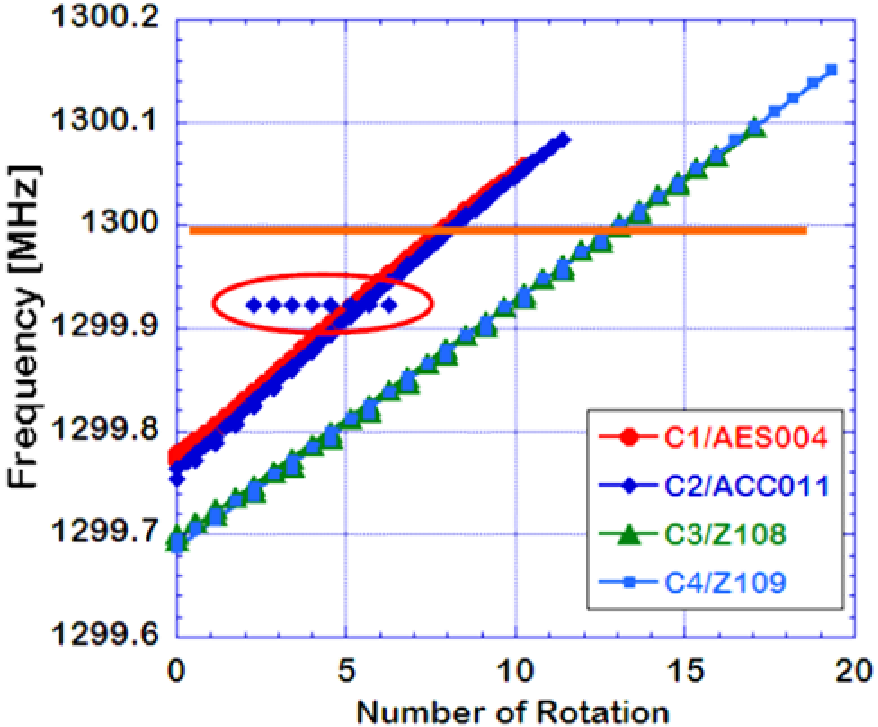
Tuning systems in details: KEK cavity units

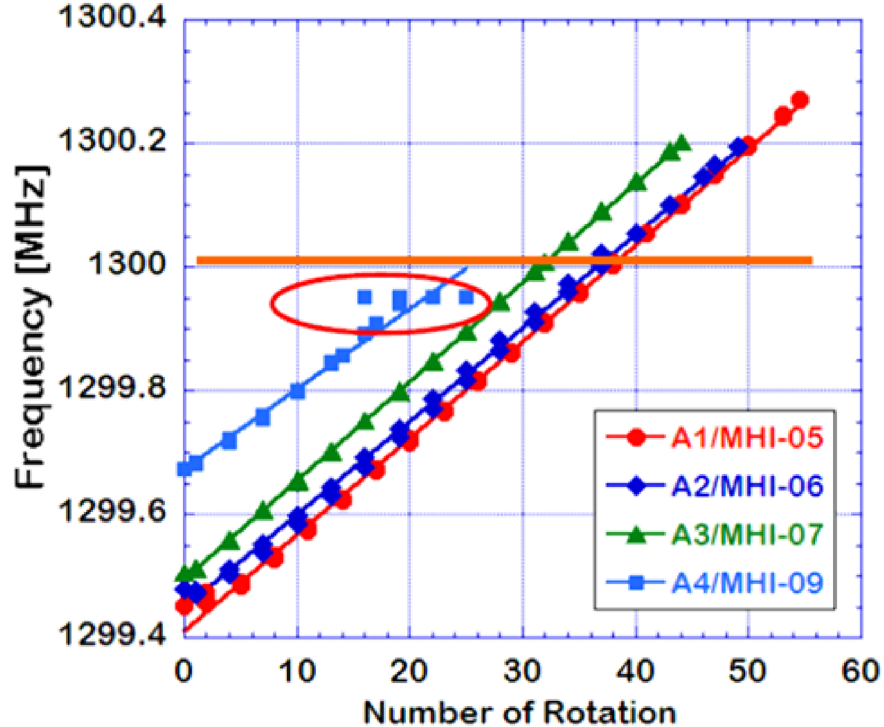
- KEK Slide-Jack Tuner rationales:
  - **Stiff design specifically developed for KEK TESLA-like cavities**
  - **The tuning driving action is generated outside the vessel and transferred to a feed-trough shaft: no motor units is required to be install inside the module.**
  - **The longitudinal strain 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

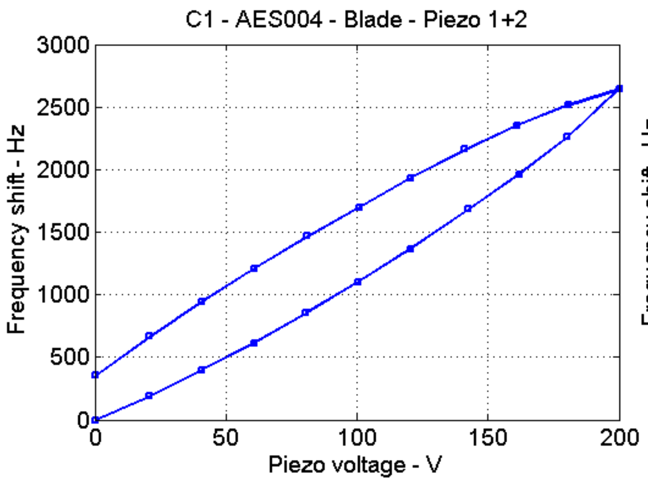


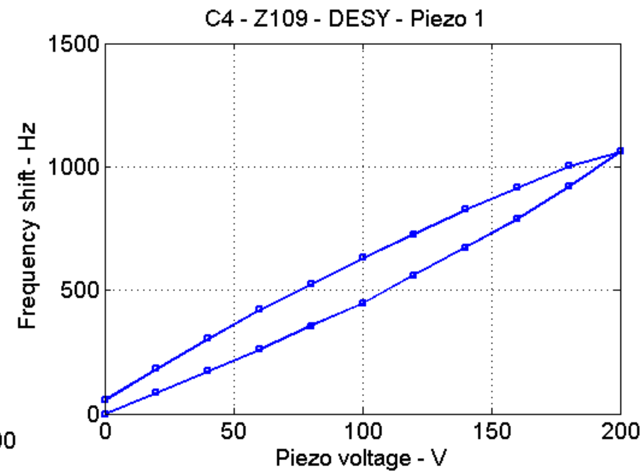


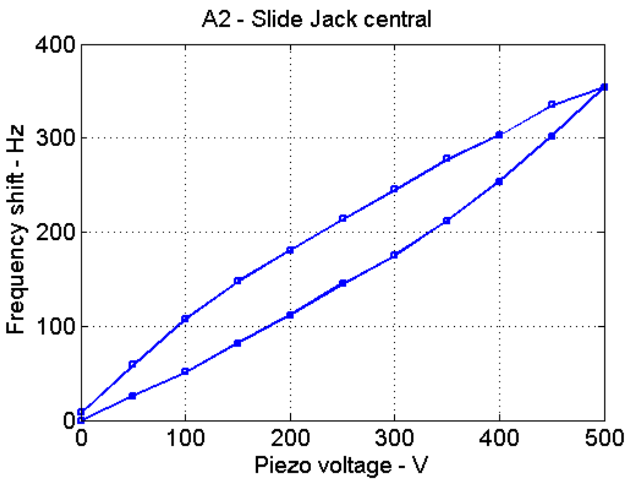
	Blade Tuner (C2)	DESY tuner (C4)	Slide-Jack tuner (A1)
Coarse tuning range measured (expected value)	330 kHz 12/22 turns (600 kHz)	450 kHz 19/23 turns (500 kHz)	800 kHz 54/60 turns (900 kHz)
Tuning sensitivity at 1.3 GHz (expected value)	25 kHz/spindle turn	20 kHz/spindle turn	15 kHz/spindle turn
	1.4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

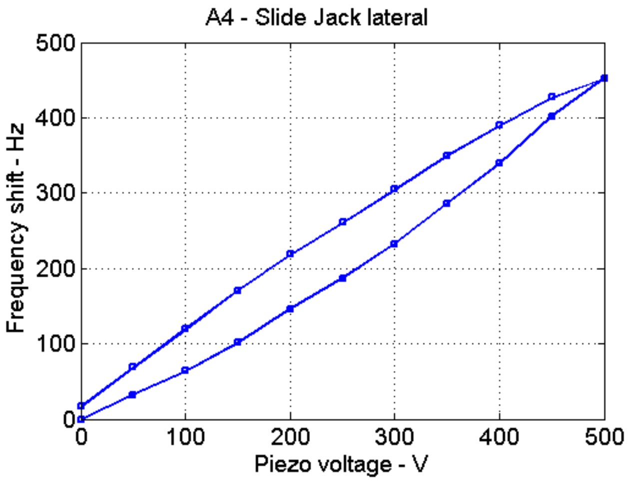
Selection of piezo DC response curves



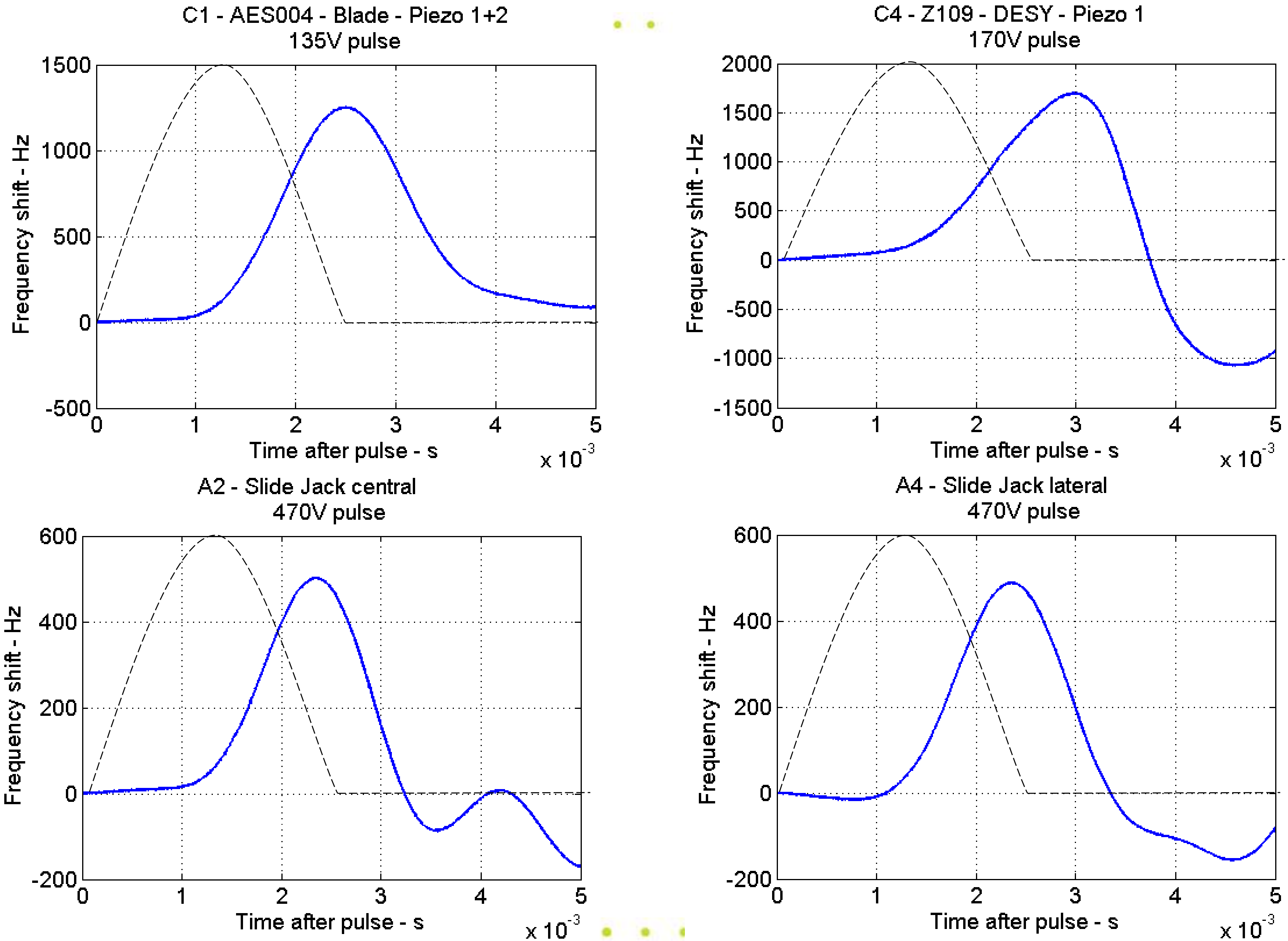


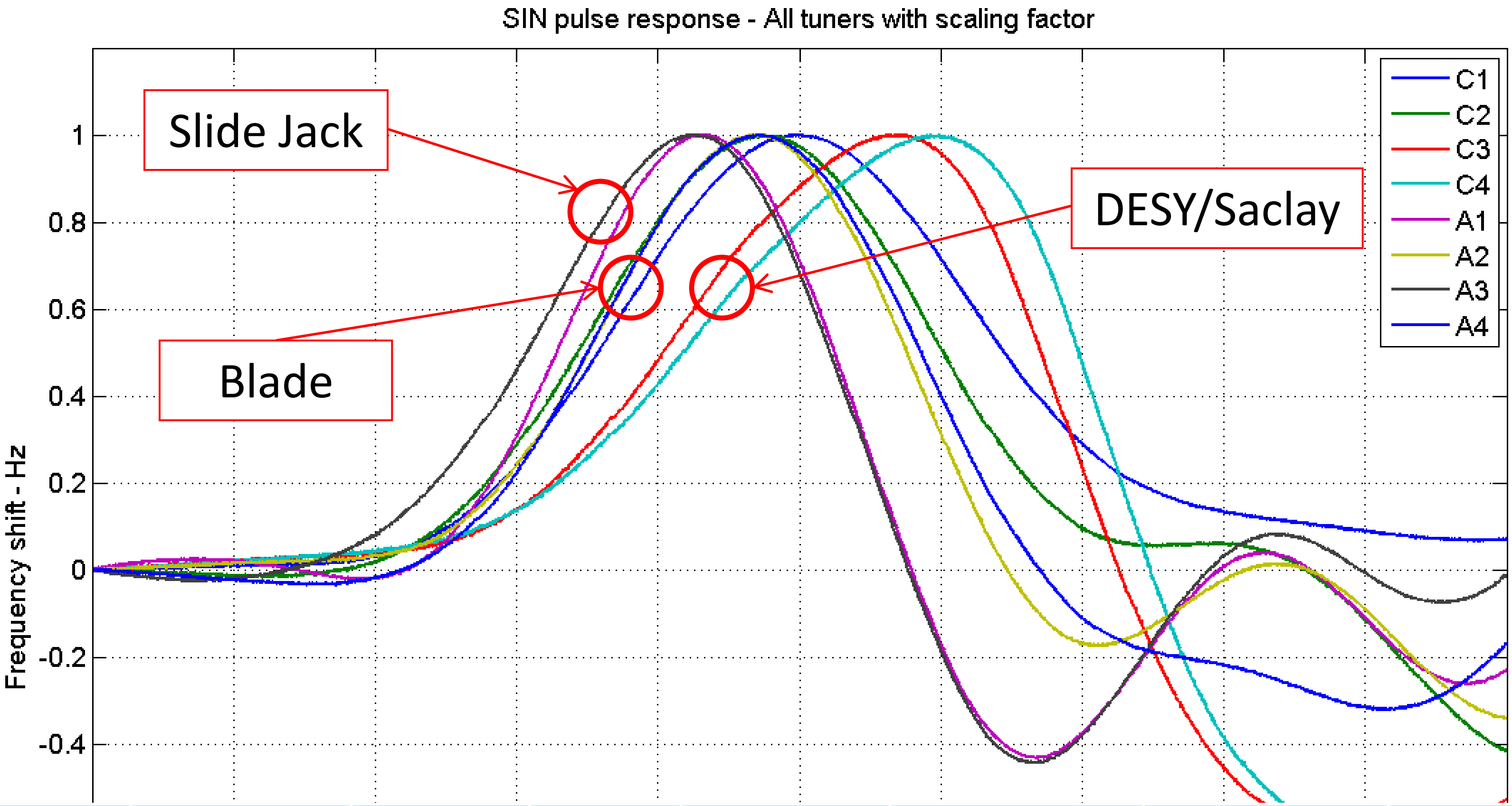


Cavity	Maximum nominal piezo voltage [V]	Piezo configuration	Maximum applied voltage [V]	Frequency shift [Hz]
C1-Blade	200	1+2	200	2650
C2-Blade	200	1	200	610
C3-DESY	200	2	200	1010
C4-DESY	200	1	200	1060
A1-S.J cent.	1000	-	500	190
A2-S.J cent.	1000	-	500	350
A3-S.J lat.	1000	-	500	210
A4-S.J lat.	1000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



Selection of SIN pulse responses

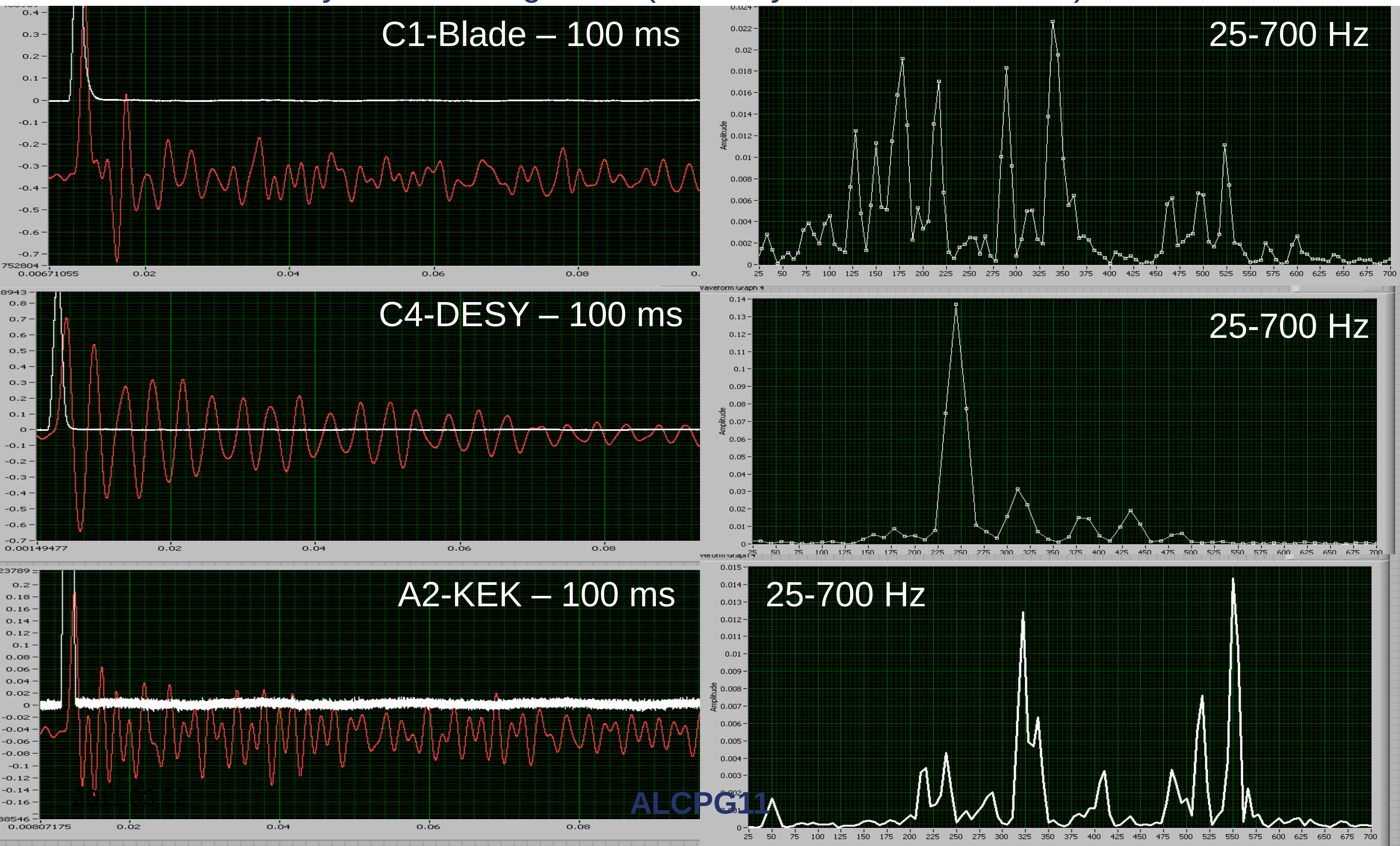




Cavity-Tuner	Max. piezo voltage [V]	Load C at 2 K [μF]	Piezo Config.	SIN pulse amp. [V]	Max. Freq. shift in 1 ms [Hz]	Best lead from pulse start [ms]	Dyn. over Static detuning ratio
C1-Blade	200	4.1	1+2	135	1040	1.31	0.6
C2-Blade	200	3.9	1+2	100	590	1.24	1
C3-DESY	200	2.0	2	180	1100	1.58	1.2
C4-DESY	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

Spectral analyses

On a larger time scale, piezo response analyses reveal dynamics of different cavity systems through FFT (courtesy of Y. Pischalnikov):



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.**

Resuming all LFD measurements

- RF setup:
  - 0.54 ms rise-time (QL=2.4E+6)
  - 1.0 ms flat-top
  - 5 Hz repetition rate
- The K_{LFD} parameters:
  - K_{LFD} computed along the full pulse
  - K_{LFD}^{RS} computed along the rise-time
  - K_{LFD}^{FT} computed along the flat-top

$$\Delta f = (f_{t1} - f_{t0}) = -k \cdot E_{acc.}^2$$

$$[K] = \left[\frac{Hz}{\left(MV/m\right)^2} \right]$$

	FNAL tests			KEK tests		
	$\boldsymbol{K_{LFD}}$	K_{LFD}^{RS}	K_{LFD}^{FT}	$\boldsymbol{K_{LFD}}$	K_{LFD}^{RS}	K_{LFD}^{FT}
C1-Blade	**0.95**	0.54	0.41	**0.90**	0.46	0.43
C2-Blade	**0.75**	0.38	0.37	**0.83**	0.31	0.51
C3-DESY	**1.12**	0.50	0.62	**1.22**	0.49	0.73
C4-DESY	**1.14**	0.50	0.64	**1.00**	0.41	0.59
A1-S.J cent.				**0.70**	0.56	0.14
A2-S.J cent.	**0.72**	0.50	0.22	**0.66**	0.49	0.17
A3-S.J lat.	**0.70**	0.60	0.10	**0.69**	0.55	0.14
A4-S.J lat.				**0.79**	0.50	0.29

Comments:

- Data are correctly correlated and coherent
- The same sharp harmonic response observed during CW test in DESY systems is affecting also now its behavior: higher K_{LFD} due to large overshooting!
- The very low K_{LFD}^{FT} for KEK cavity is clear a proof of the higher system stiffness
- The K_{LFD}^{RS} is remarkably similar over different tuners. This is possibly the results of two opposite effects: Slide-Jack tuner has lower detuning but shorter rise time so the response is stronger at the beginning of the pulse.

FNAL Piezo Control System

Selected material from a review of system and results from Yuriy Pischalnikov (FNAL)

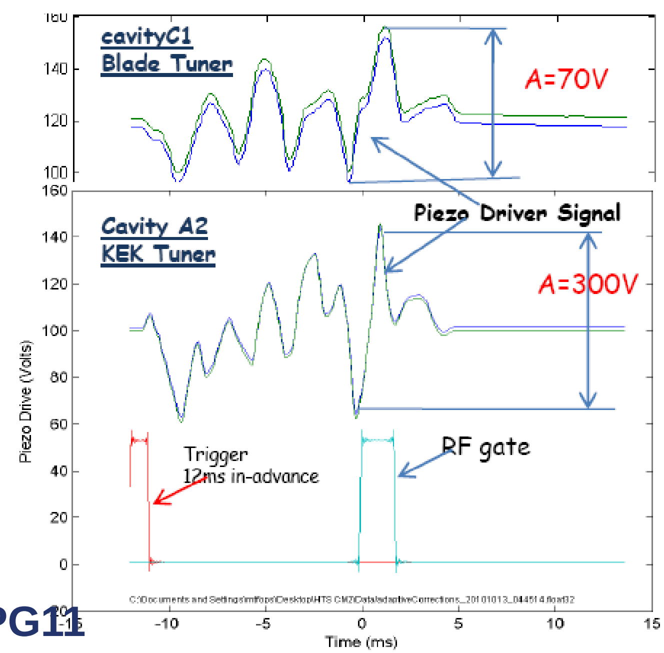
FNAL's Piezo Control System

FNAL built and deliver to KEK LFD Compensation system:
Hardware:
1,3GHz → 13MHz receivers (for cavities RF signals),
100MHz ADC for cavities RF signals,
PXI DAQ system (Processor & FPGA),
HV Piezo Drivers.
Software:
Matlab, LabView, FPGA codes.
Algorithm:
FNAL's Adaptive LS LFD Compensation Algorithm
(developed by Warren Schappert)

FNAL Adaptive LS LFD Compensation Algorithm:

-Able to maintain flat cavity phase during both part of part of RF pulse "fill" and "flattop";
-An adaptive version of the LS procedure implemented on the FNAL HTS Piezo Control System for routine Cavity/Tuner testing (and will be part of NML -CM1 piezo control instrumentation);
-During operation LS algorithm able to automatically compensate LFD as cavity was ramped up from 15 MV/m to 32 MV/m and back up again;

Piezo Impulse Calculated by LS LFD algorithm



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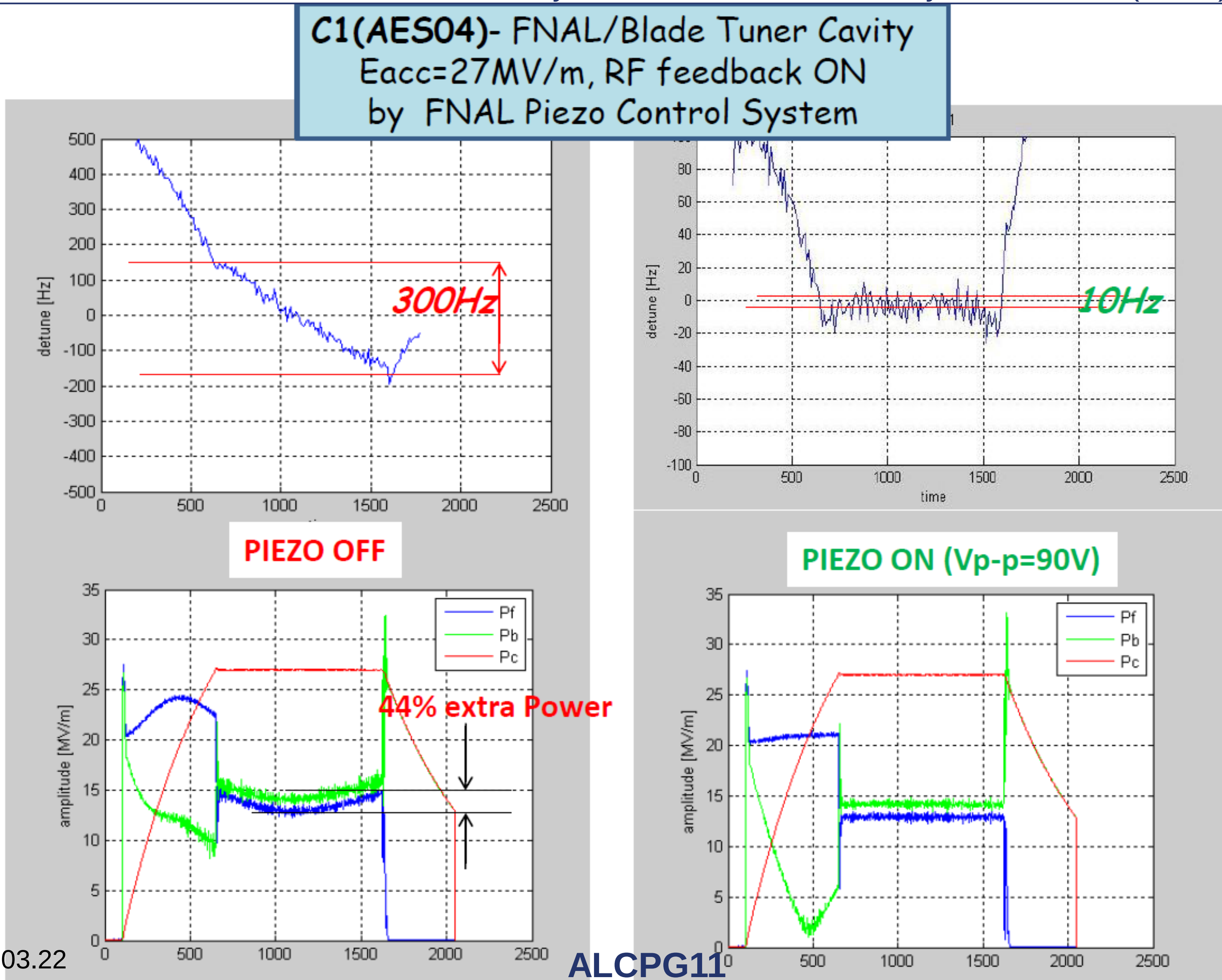

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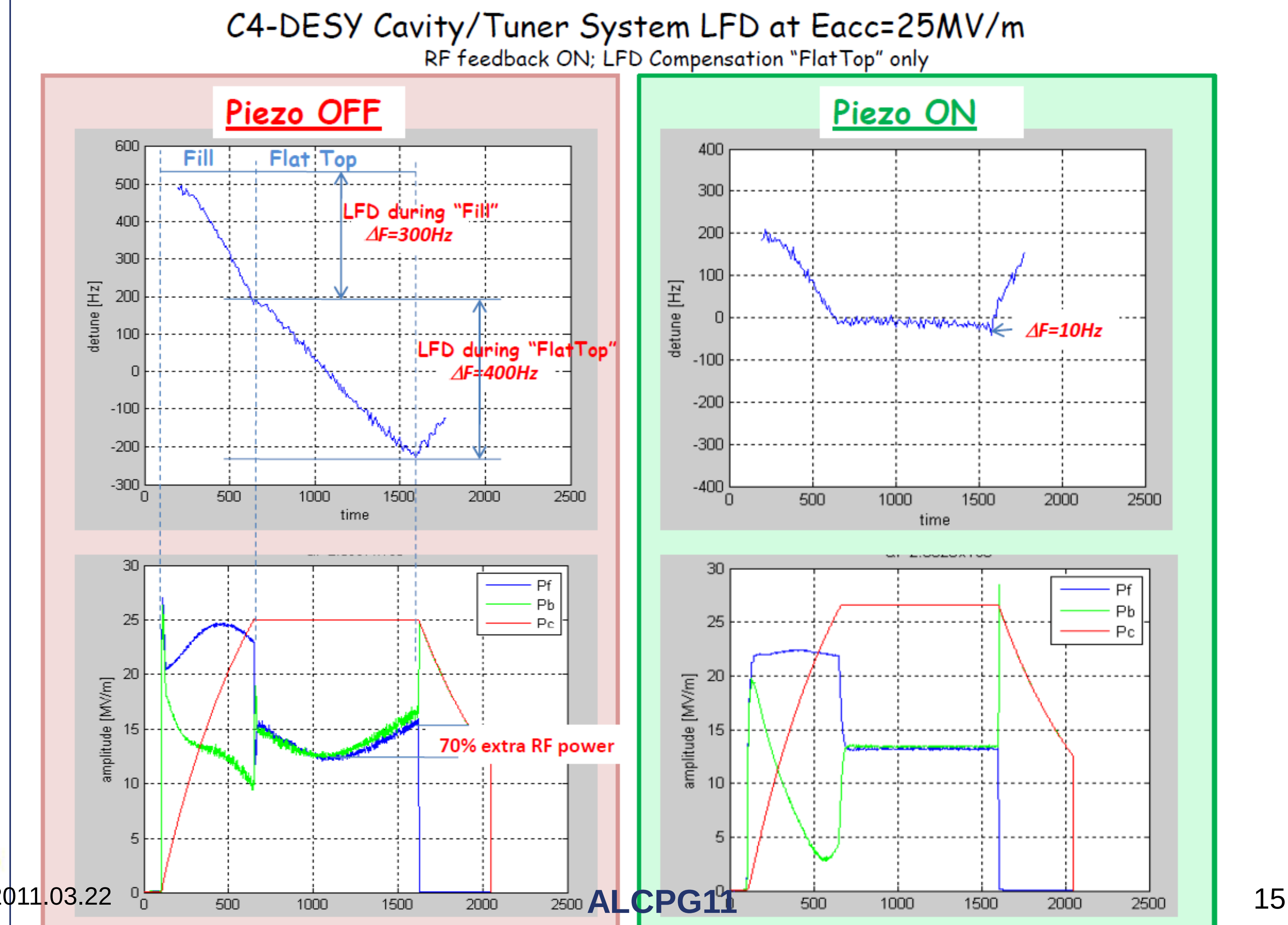

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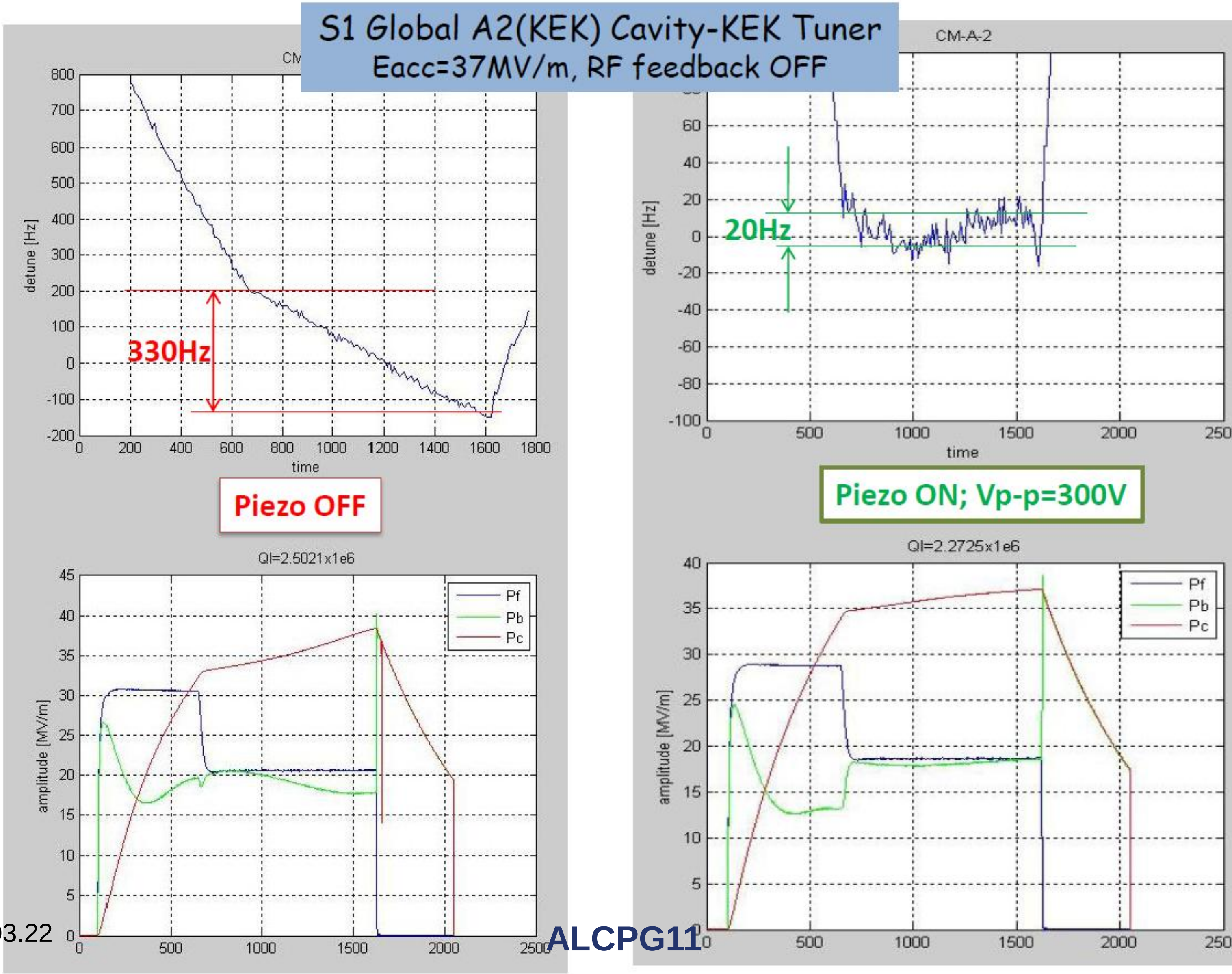
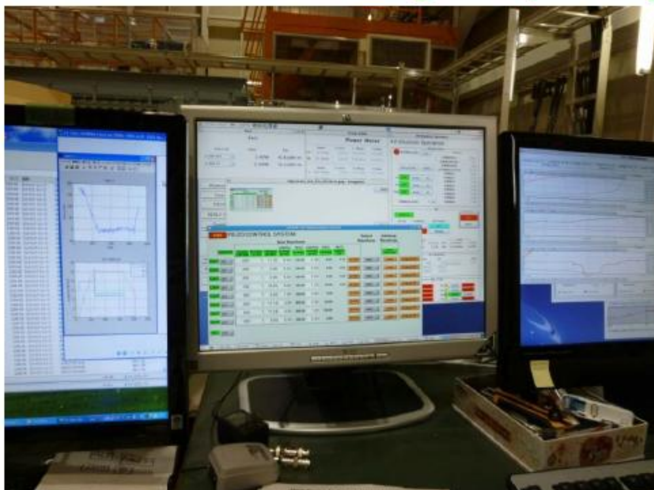


KEK Piezo Control System

Selected material from a review of system and results from Eiji Kako (KEK)

KEK Control system of Piezo Tuner

Piezo control by PC
Monitor of detuning frequency



Piezo driver for KEK cavities (+1000V)

Piezo driver for DESY/FNAL cavities (+200V)

KEK Piezo Control System

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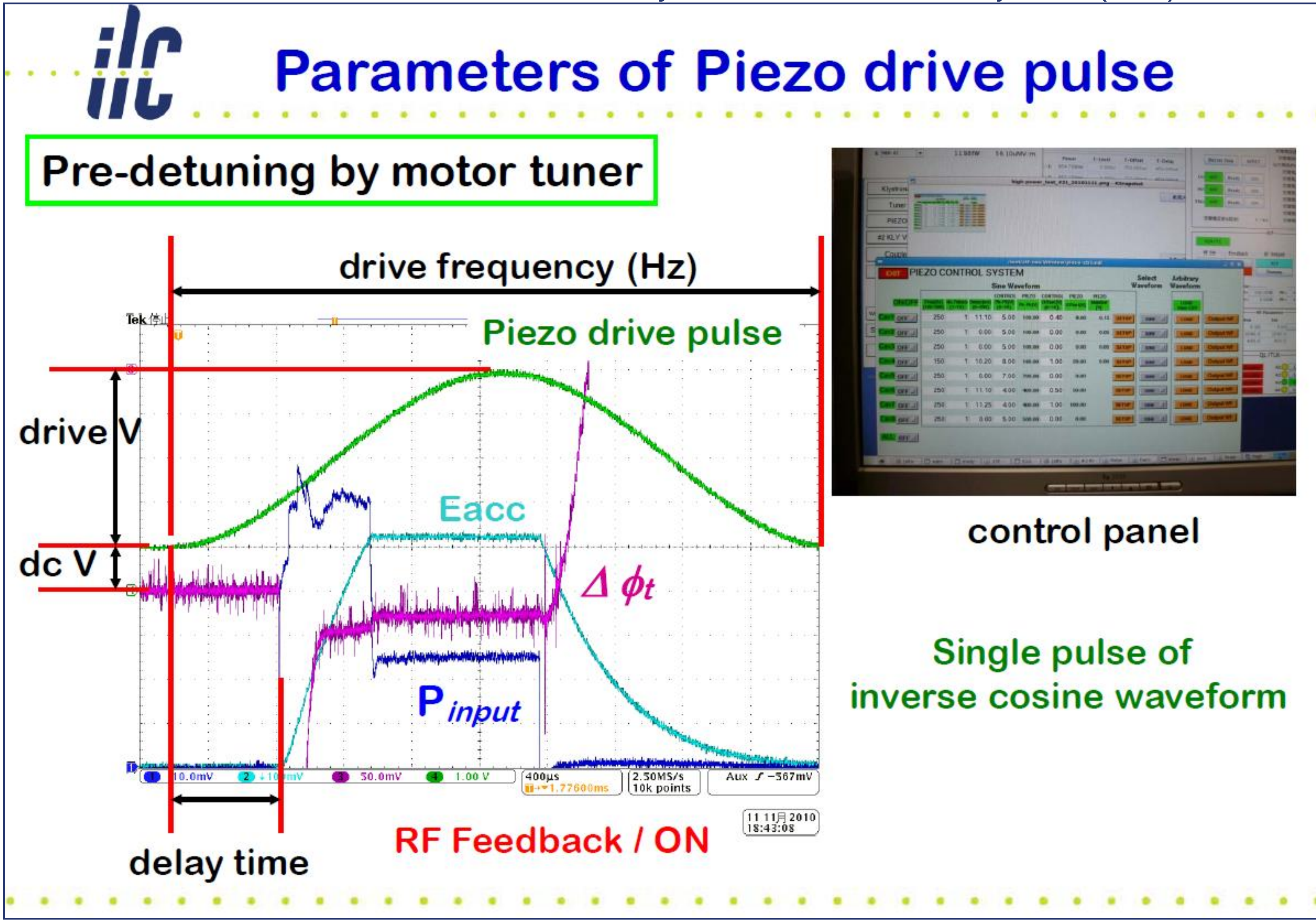

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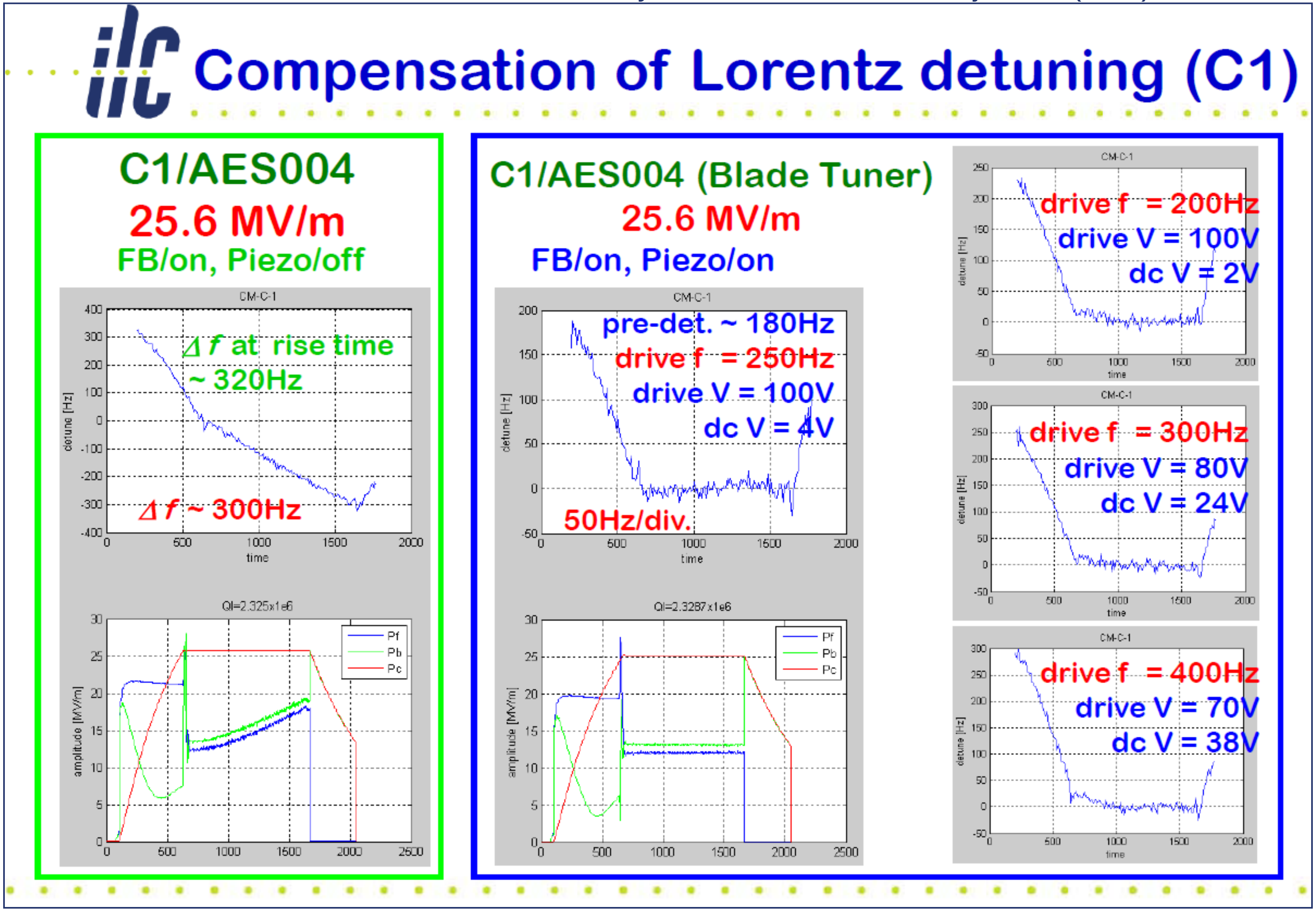

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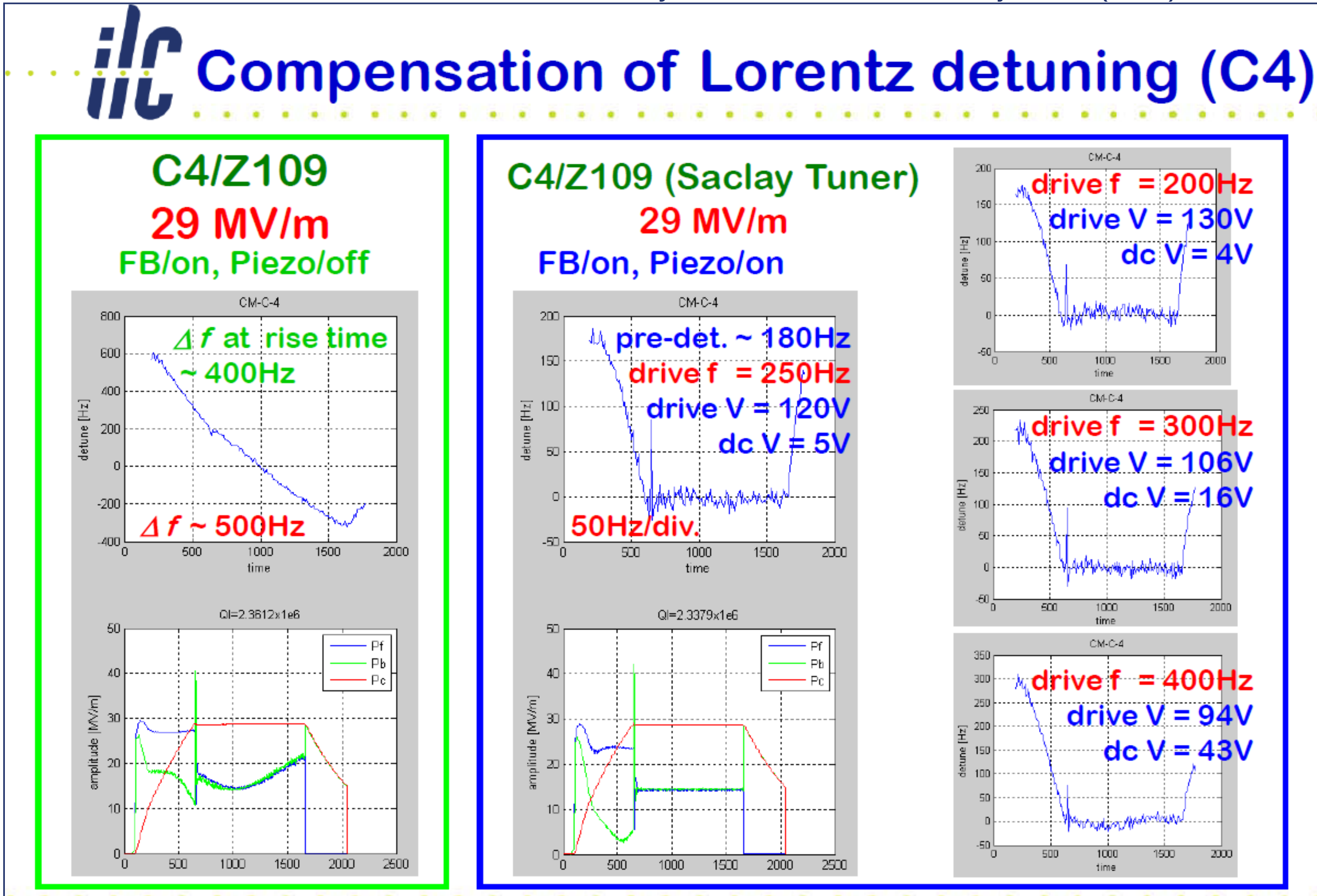

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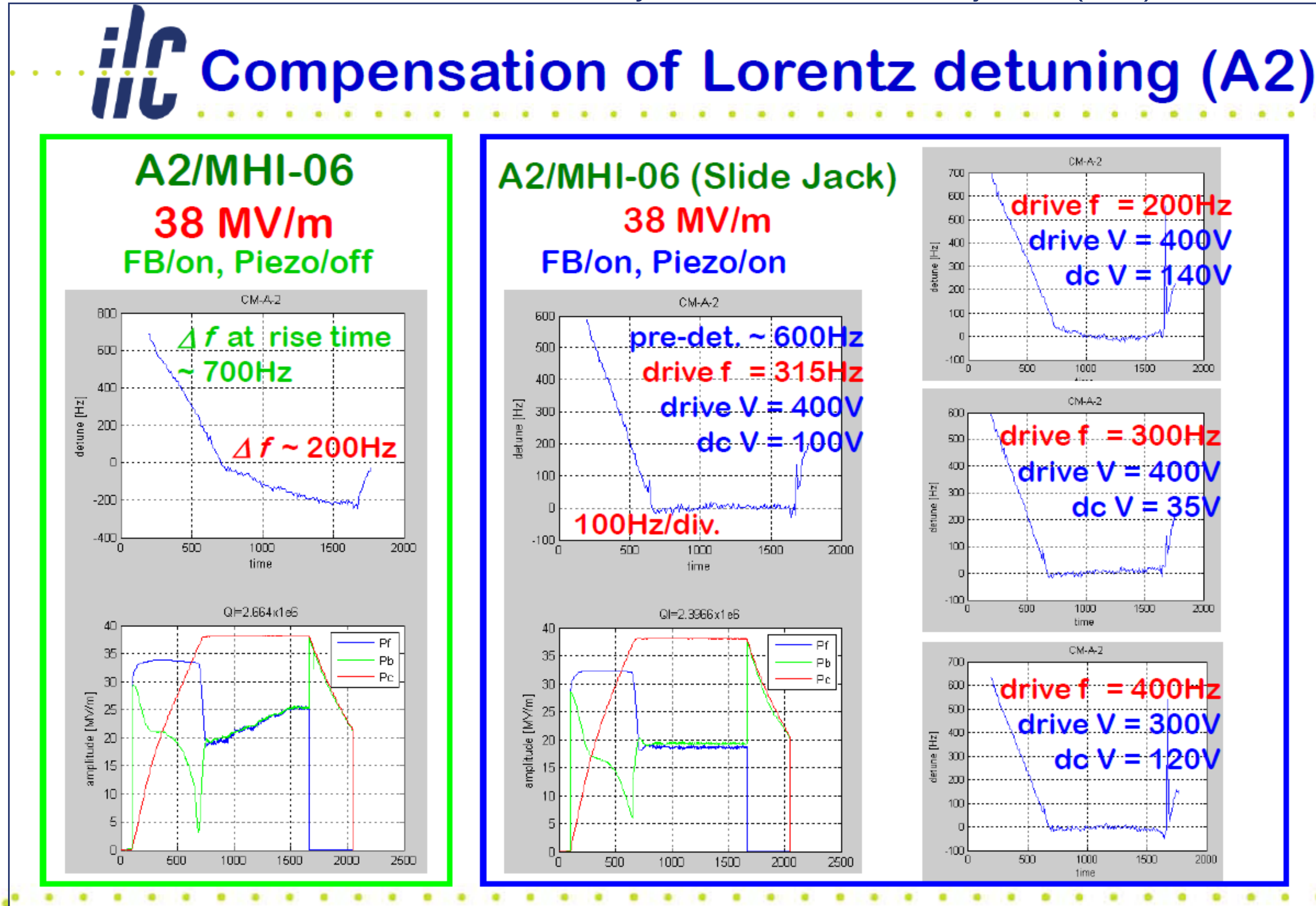

Conclusions

- Globally, each of the different models of tuning systems installed at S1-Global proved to be capable to accomplish its main goals:
  - **Statically tune the cavity with proper resolution to the target frequency**
  - **Achieve pulsed operation at maximum gradient with an active compensation of the LFD up to tens of Hz-level residual detuning.**
  - **Demonstrate to grant enough performance margin in LFD compensation in view of ILC-level target gradients.**

- Failures emerged in some key components:
  - **Details have still to be investigated but …**
  - **Stepper motors, mechanical gears or piezo actuators are well-known and substantially affordable: we don't expect observed issues to be intrinsic problems.**
  - **More likely, for S1-Global both the technical novelties present in some elements and the lack of experience on a module string could have played a major role (both INFN/FNAL and KEK systems are installed on a string here for the first time).**

- The overall S1-Global experience:
  - **Has been an outstanding possibility to operate different tuners simultaneously**
  - **The investigation of failures in tuning systems will provide a remarkable experience to improve reliability in future installations.**