



# Fabrication and Quality Control of the Frequency Tuner for the XFEL

Lutz Lilje  
DESY

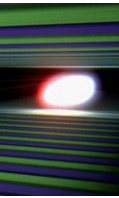
European Linear Collider Workshop  
ECFA LC2013



# Thanks!

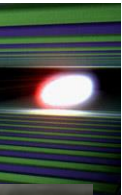
Several people contributed with support and measurements to the work presented here:

R. Paparella, A. Bosotti, C. Albrecht, K. Jensch, O. Keller, K Przygoda, M. Grecki, C. Müller and many more also within the S1 Global Test at KEK

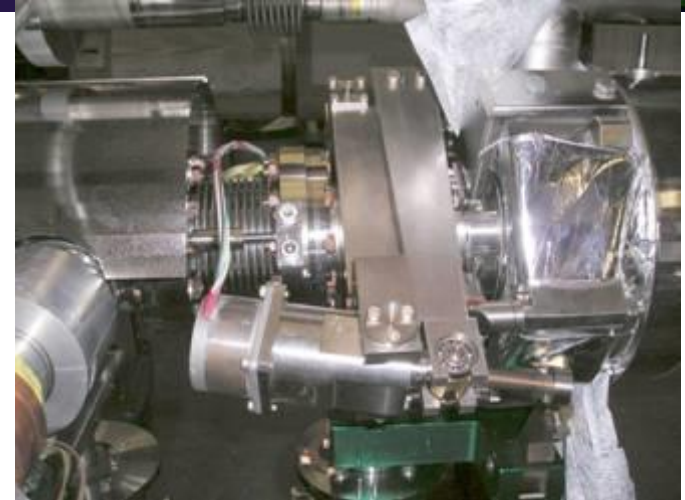


- Performance
  - Tuning range
  - Lorentz force compensation
  - Operation in FLASH
- Steps towards industrialisation
  - Mechanics
  - Motor drive
  - Piezo system
- Current status
  
- Disclaimer:
  - No details on Piezo amplifier or motor driver electronic given here
  - Developments well on-track by LLRF WP and DESY groups MSK and MCS

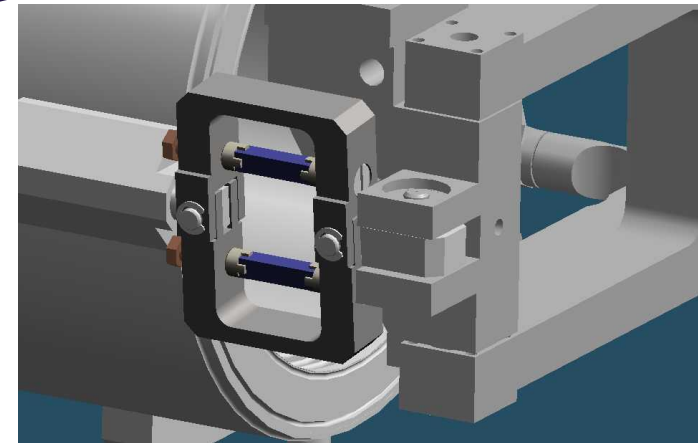
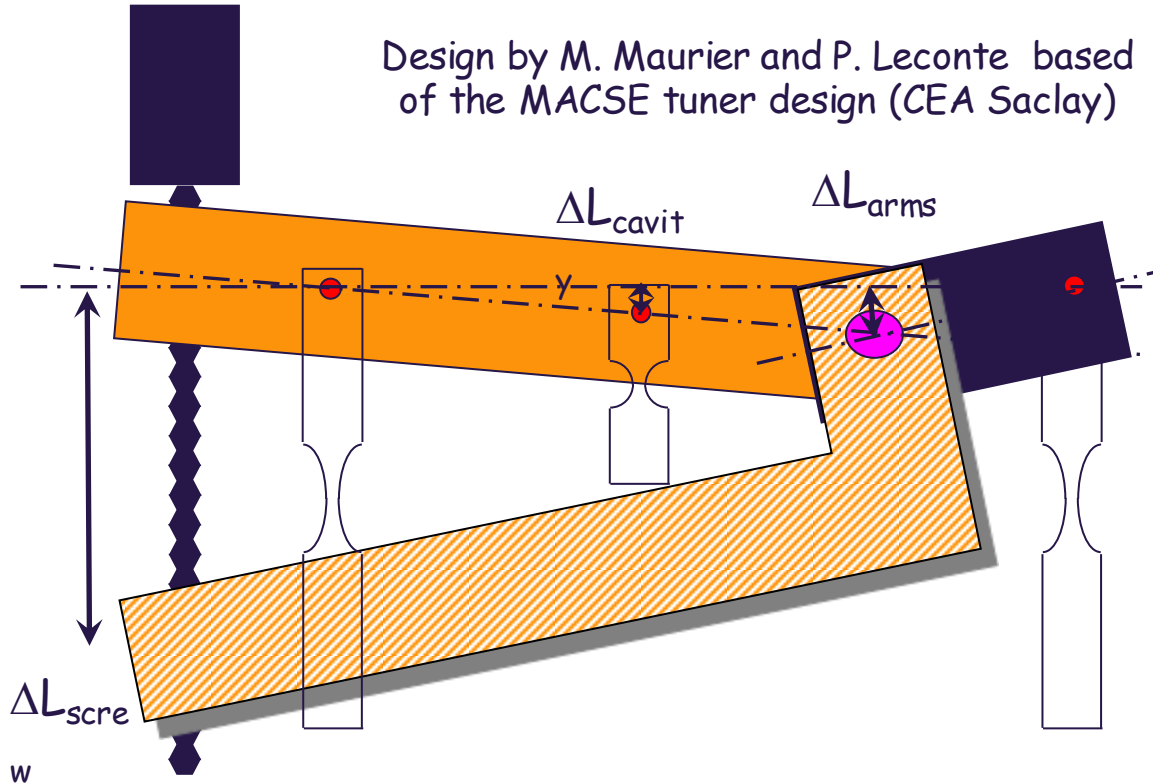
# Tuner Scheme



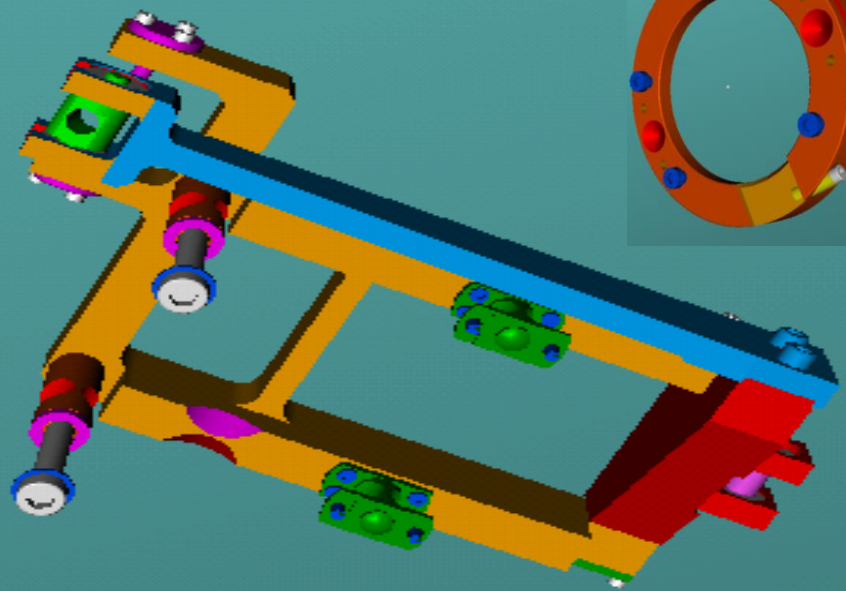
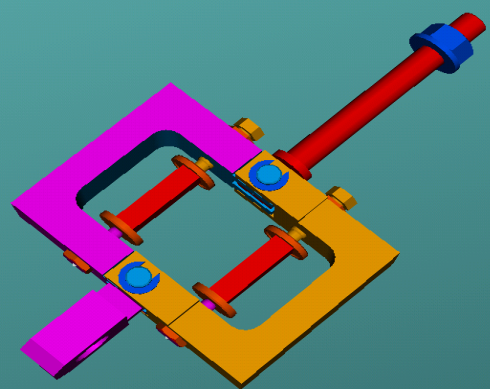
- **Current design** in use at FLASH
  - Original design by CEA
  - Fast piezo detuning introduced by DESY



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



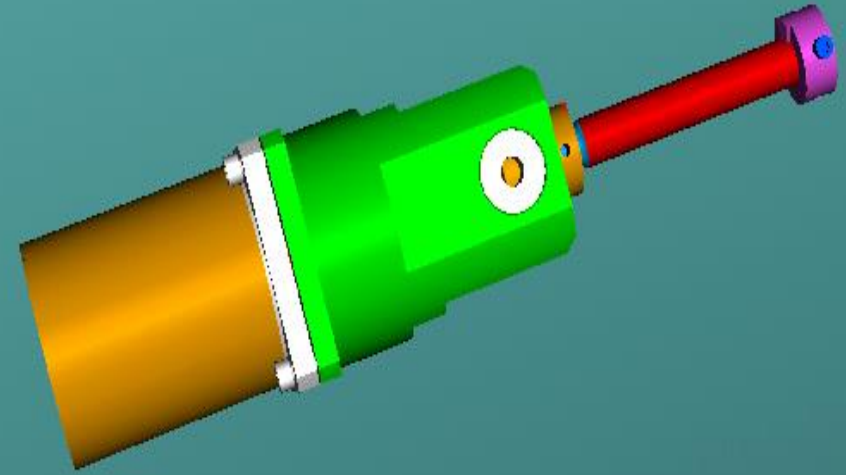
# Tuner Parts: Overview



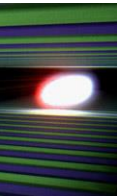
Piezo System

Mechanics

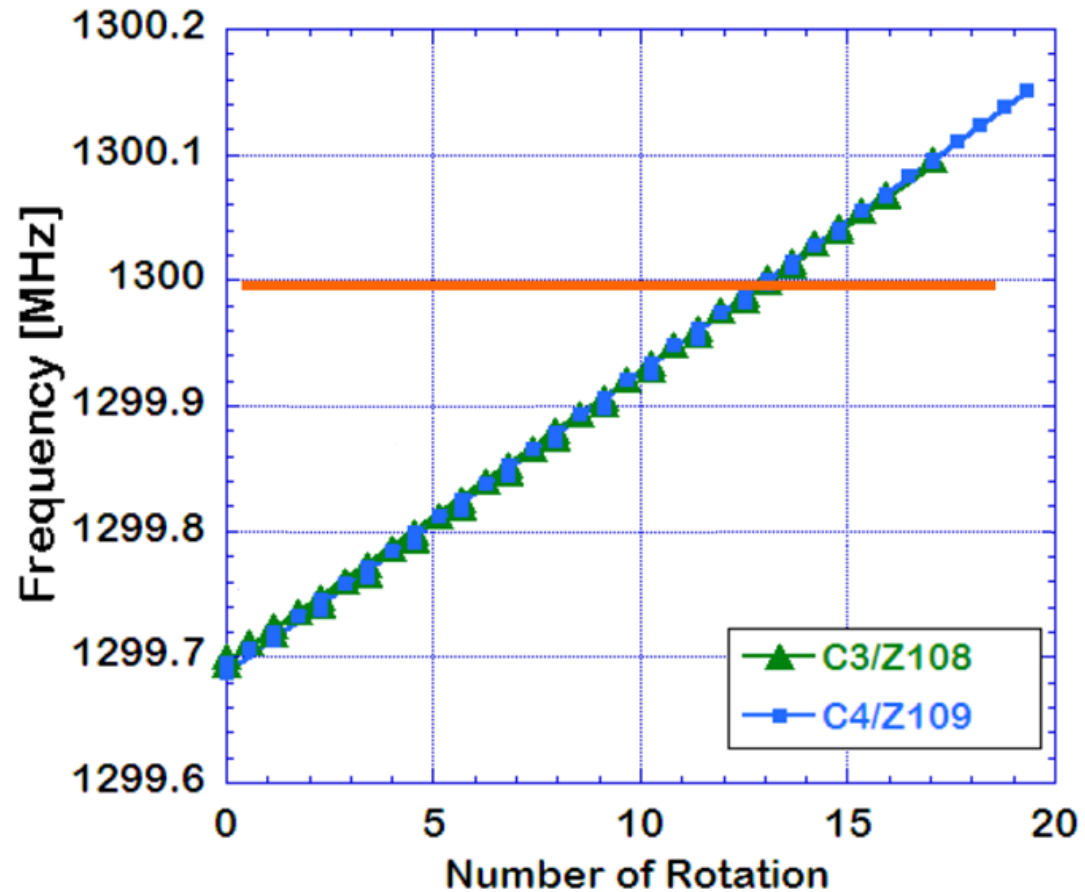
Drive Unit



## Mechanical tuner: Performance demonstrations

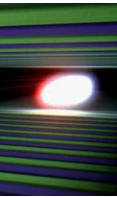


- Tests of motor with gearbox
- Tuning range test
  - Test at S1 Global shows more than 400 kHz tuning range
    - ➔ DESY tests more than 600 kHz
  - Expected from cavities is ~200 kHz
- Hysteresis is low
- Endurance tests under operating conditions (cold in vacuum)
  - More than 20 Million motor steps corresponding to 20 years of operation
- Motors survived even the Isolation Vacuum crash test

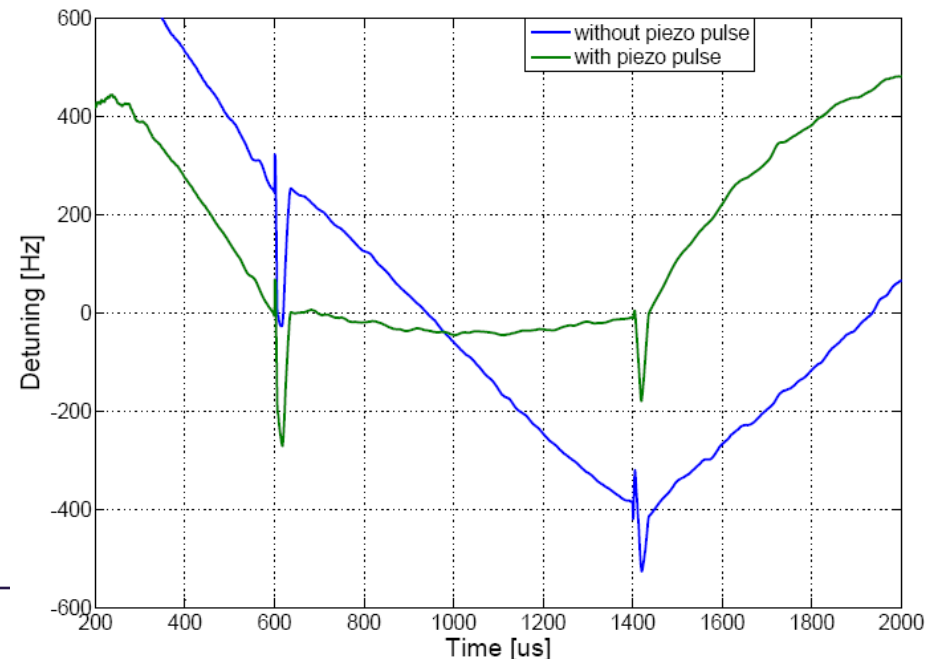
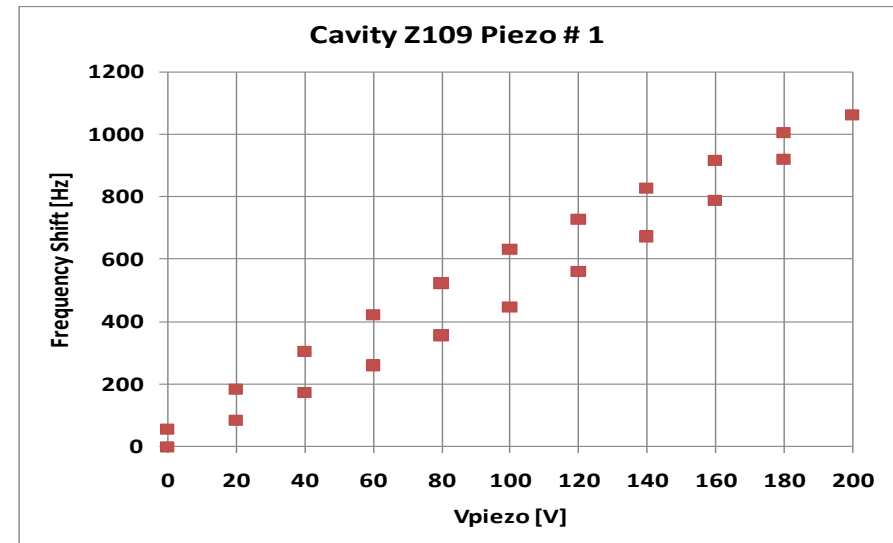


■ Courtesy of KEK

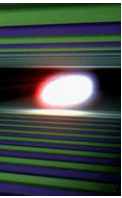
## Piezo system test



- Static detuning  $\sim 1$  kHz
- Demonstration of Lorentz force detuning compensation
  - 35 MV/m compensated
- Endurance testing
  - No problems expected
  - Even after exposure to Helium atmosphere
  - Radiation exposure no problem
- Permanent operation in FLASH since 1-2 years
  - Not yet fully evaluated in terms of endurance testing



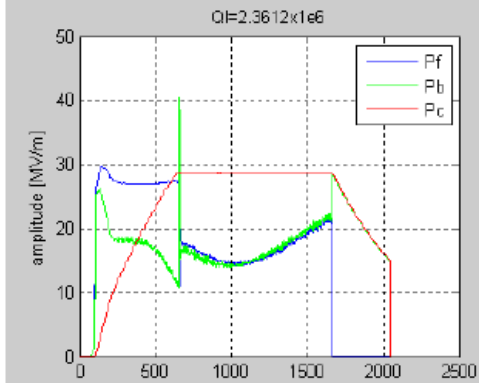
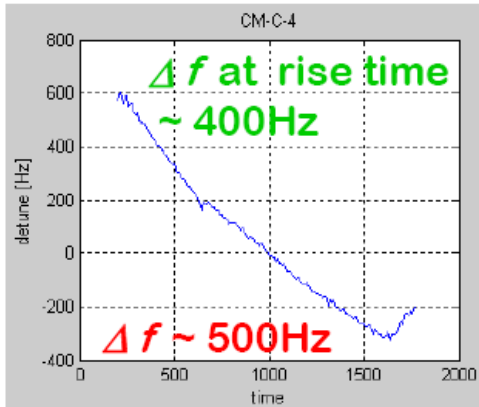
# S1 Global results of Piezo tuner



**C4/Z109**

**29 MV/m**

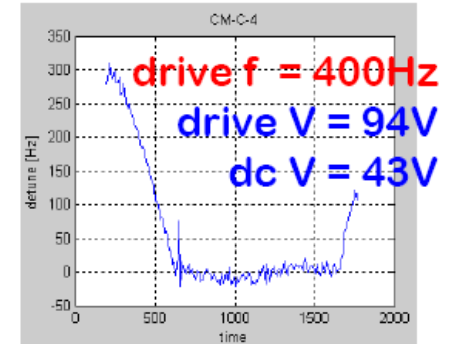
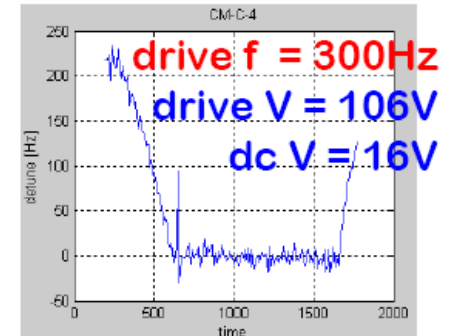
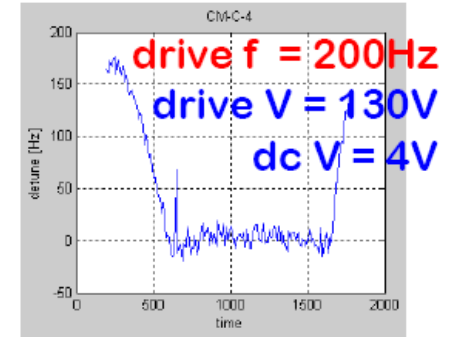
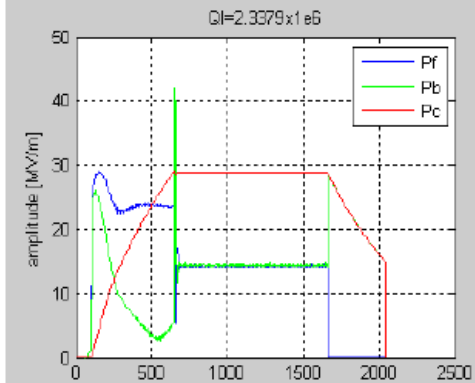
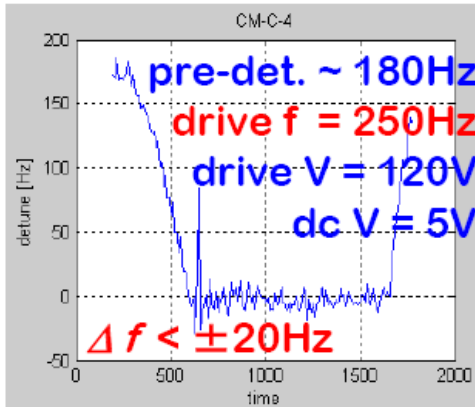
**FB/on, Piezo/off**



**C4/Z109 (Saclay Tuner)**

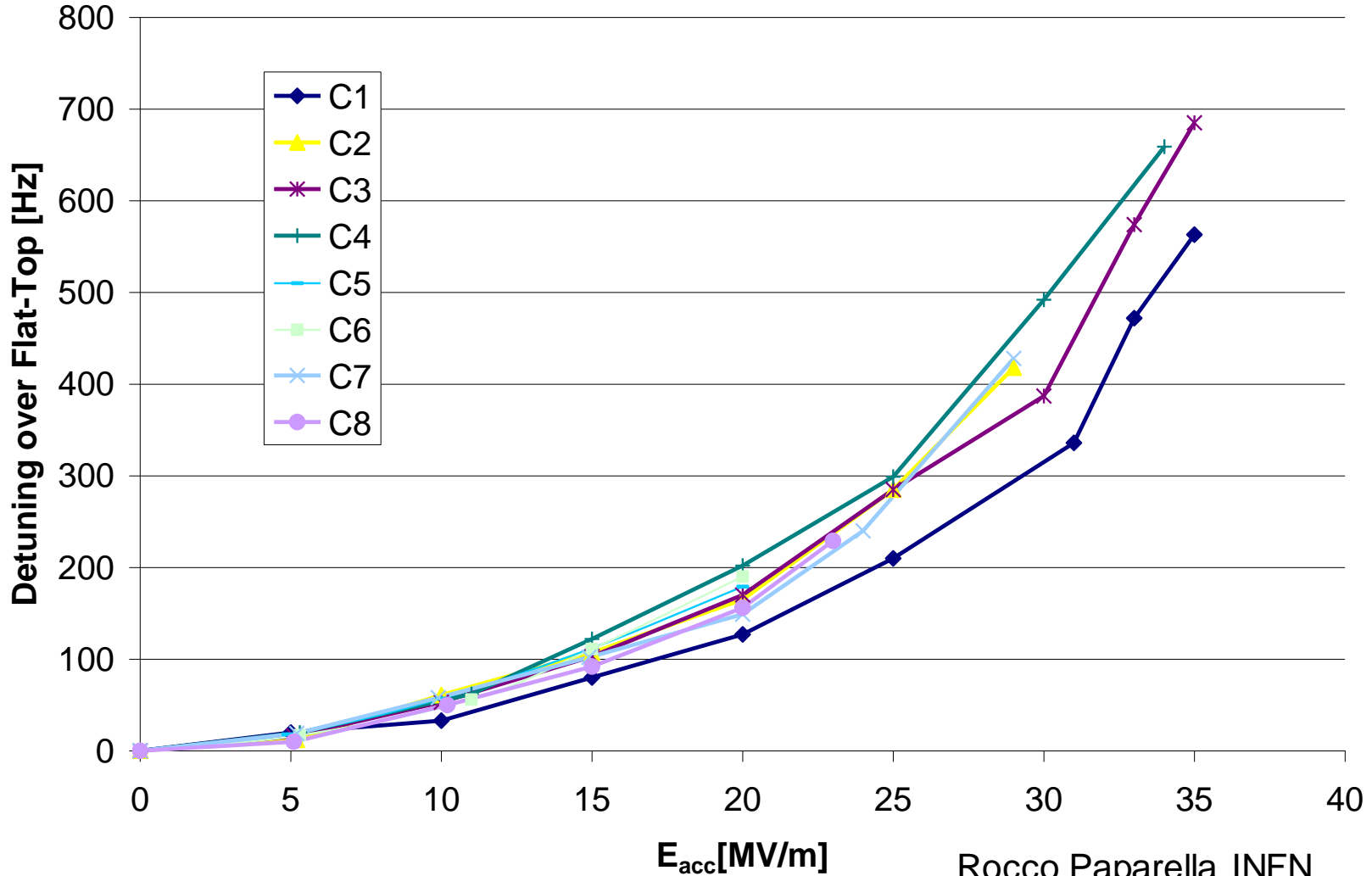
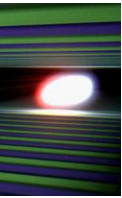
**29 MV/m**

**FB/on, Piezo/on**





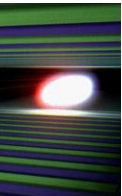
# Lorentz Force Detunings in Module 6



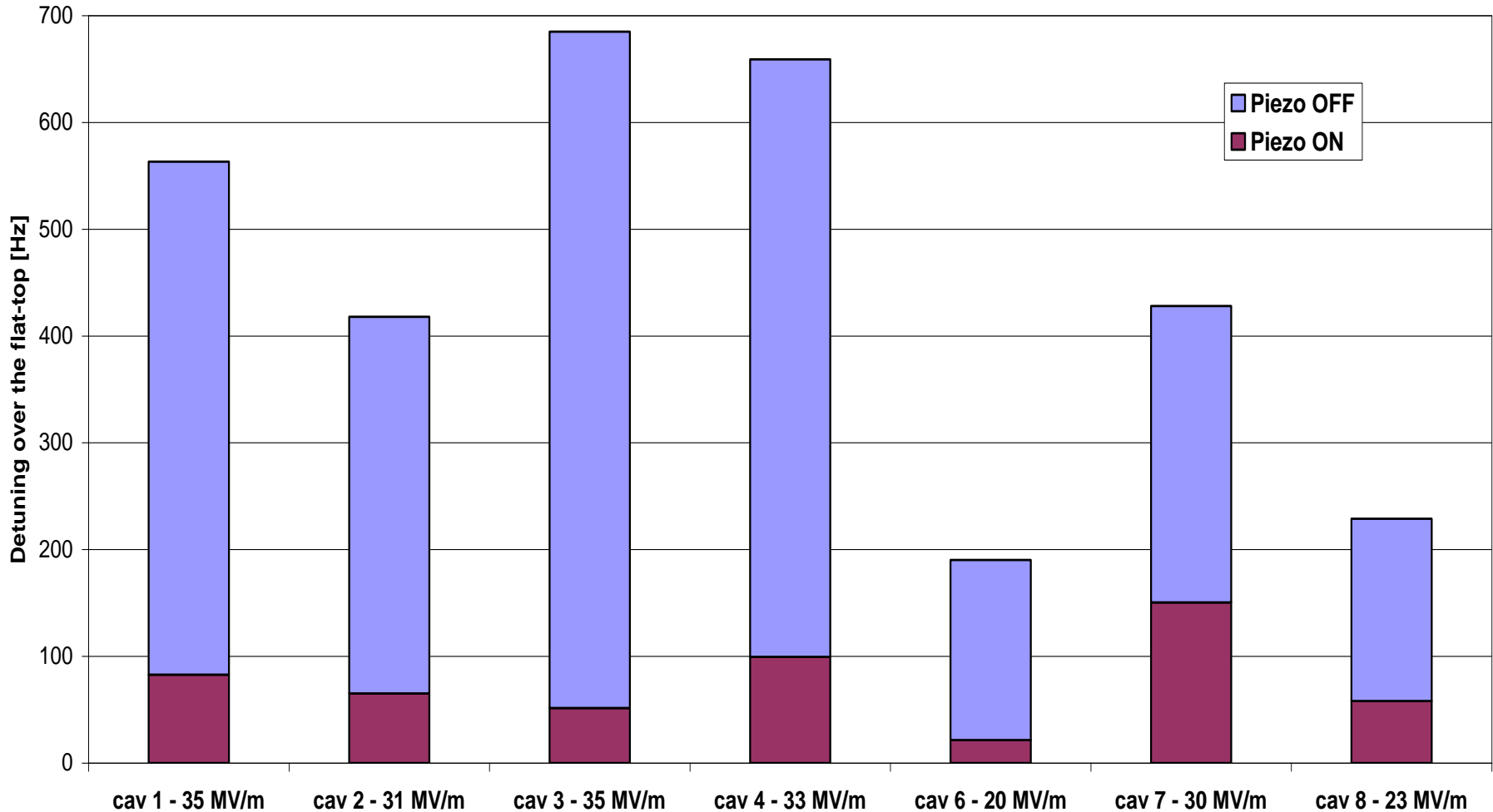
Rocco Paparella INFN

Lutz Lilje DESY -MPY- 2007

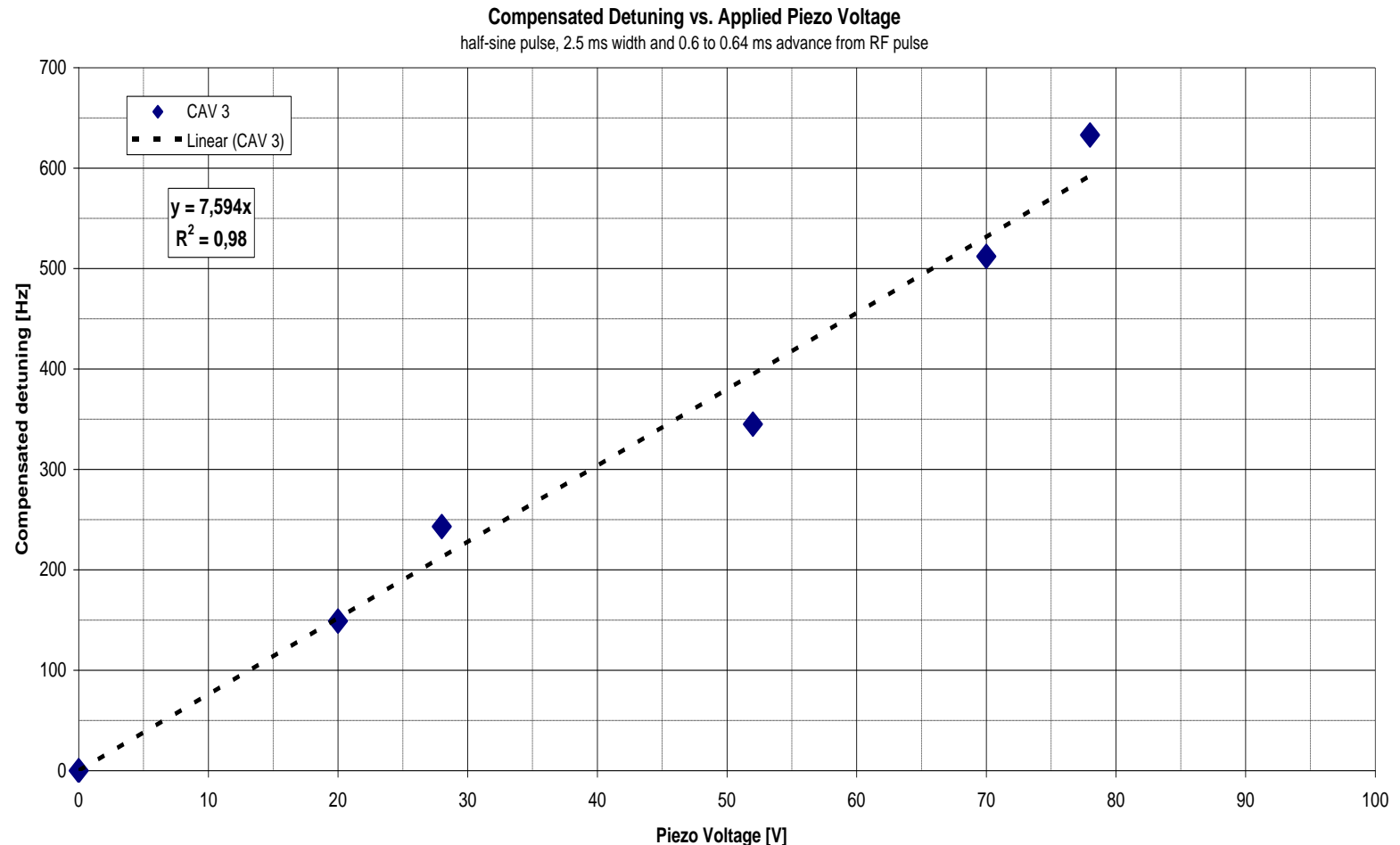
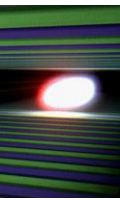
# TTF Module 6: Compensated Detuning per Cavity



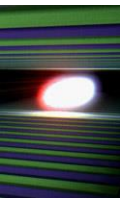
Maximum Lorentz Force detuning compensation results



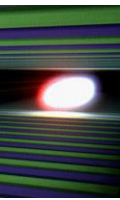
# Voltage on Piezo Needed for Compensation



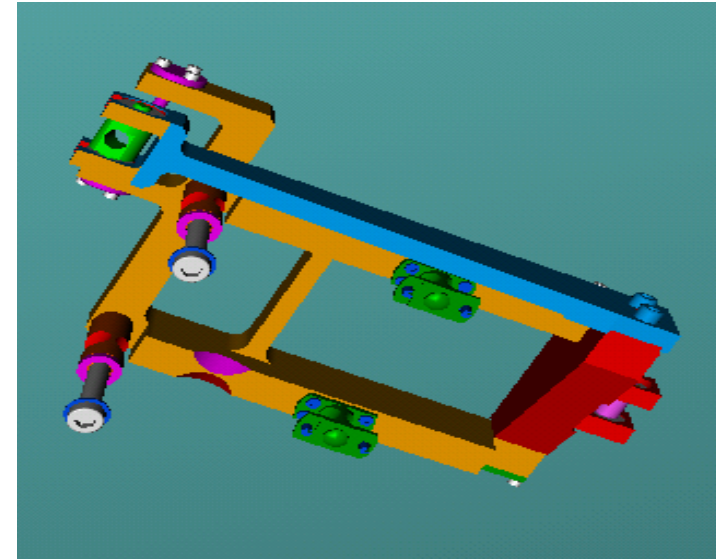
- Piezo Voltages within margin
  - ➔ maximum PI piezo voltage of 120 V at room temperature
  - ➔ Could also use bipolar operation, but not needed



- Mechanics
- Drive unit
- Piezo system



- Mechanics supplied by CEA
  - Adapted to local supplier in France
- Cost reduction
- Material quality
  - Steel with low permeability needed
- Therefore
  - Prototypes with companies experienced in mass production of precision machined pieces (for Airbus etc.)
- Conclusions
  - Several simplifications on the detailed drawings
  - Relaxed tolerances to reduce cost for precision machine time
  - Good basis for a successful call for tender



# Industrial fabrication of mechanics

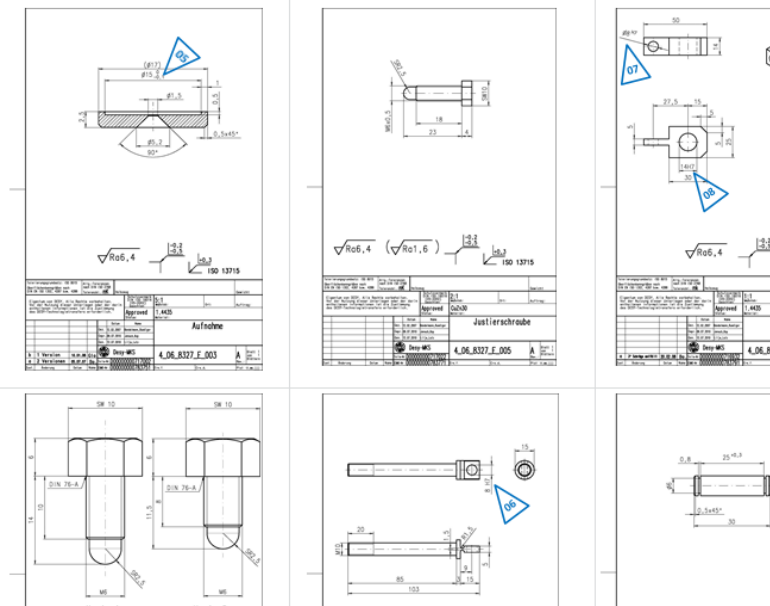
- Contract awarded to Astro- und Feinwerktechnik, Berlin
  - Minor adaption of drawings
  - After initial problems with material smooth production
- Quality control
  - Agreement on ,essential' measures
  - Pre-series completely cross-checked at DESY
  - Piezo fixture incoming check at Piezo company
  - QC protocols delivered into DESY EDMS system by company

EDMS-ID	
Number	
Name	
Description	
Location	Transportation
Project	XFEL_WP07_AstroFeinwerktechnik
Team	XFEL_WP07_AstroFeinwerktechnik_Team
TeamFolder	Fabrication Documents

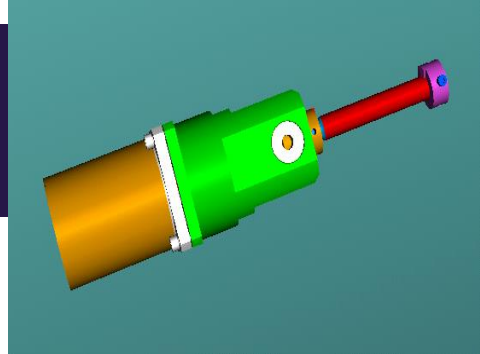
Datum	19.01.2012
Ersteller	Seidel
Herstellerei	Dummy

Dimensionsprüfung				
Zu prüfende Dimensionen s. Zeichnung		Stückzahl	passed/failed	Bemerkung
Spannbügel 1	3 06 8327 / E.001	1	failed	Los 1 (Vorserie)
Spannbügel 2	3 06 8327 / E.002	1		Los 1 (Vorserie)
Aufnahme	4 06 8327 / E.003	4		Los 1 (Vorserie)
Sechskantschraube mit Kugel	4 06 8327 / E.004 - Pos. B	2		Los 1 (Vorserie)
Justierschraube	4 06 8327 / E.005	2		Los 1 (Vorserie)
Gelenkbolzen	4 06 8327 / E.006	1		Los 1 (Vorserie)
Lasche	4 06 8327 / E.007	1		Los 1 (Vorserie)
Zylinderbolzen	4 06 8327 / E.008	2		Los 1 (Vorserie)
Spezialmutter	4 06 8327 / E.009	2		Los 1 (Vorserie)

Permeabilitätsprüfung				
Magnetisierbarkeit $\mu_r < 1,05$		Stückzahl	passed/failed	Bemerkung
Spannbügel 1	3 06 8327 / E.001	1		
Spannbügel 2	3 06 8327 / E.002	1		
Aufnahme	4 06 8327 / E.003	4		
Sechskantschraube mit Kugel	4 06 8327 / E.004 - Pos. B	2		
Justierschraube	4 06 8327 / E.005	2		
Gelenkbolzen	4 06 8327 / E.006	1		
Lasche	4 06 8327 / E.007	1		

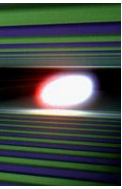


# Challenges for industrialisation: Motor and gear box



- Basic idea from CEA: Step motor and harmonic drive
  - Initial tests failed due to insufficient coating
    - Lubrication under cold vacuum conditions tricky
  - DESY in-house development on coatings
    - Parts purchased via different sources
    - Integration/Assembly at DESY
  - Second motor supplier came into play later than expected
    - Cold testing possible at vendor
- Therefore:
  - Training for at least two companies to deliver complete and tested drive units:
    - Motor, gear box, thread with nut
    - Test temperature liquid nitrogen, units under load
  - Use prototyping phase
- Conclusion
  - Both vendors were capable to fulfill XFEL requirements
    - E.g. Life-Time

# Industrial fabrication of drive unit



- Contract awarded to Harmonic Drive, Limburg
  - Minor adaption of drawings
- Quality control
  - Agreement on few ,essential' mechanical measures
  - Room temperature and at liquid N2 temperature tests
    - ➔ Record current when
      - Beginning of movement
      - Loss of steps
      - Total number of steps
  - QC protocols delivered into DESY EDMS system by company

EDMS-ID	
Manufacturer's Serial Number	
Name	
Description	

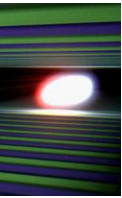
Project	XFEL_WP07_HarmonicDrive
Team	XFEL_WP07_HarmonicDrive_Team
TeamFolder	Fabrication Documents

Dimensionale Prüfung*	Beschreibung	Ergebnis
Q1	Gesamtlänge AE [210,6 +/- 0,1 mm]	OK
Q2	Wärmeleitblech [77,3 mm maximal]	OK
Q3	Wärmeleitblech [67,3 mm maximal]	OK
Q4	Durchmesser [9 -0,005/-0,014 mm]	OK
Q5	Abstand [14 +/-0,2 mm]	OK
Q6	Kabellänge [450 +/- 20 mm]	OK

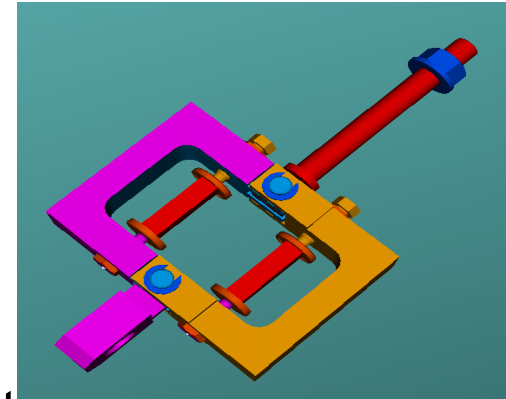
Prüfung Ausgangstest	Beschreibung	Ergebnis
P1 [RT]	Datum:	ok
P2 [RT]	Motor, elektrischer Widerstand [Ohm]:	NOK
P3 [RT]	Motor, Induktivität [Henry]:	OK
P4 [RT] [200N Sindellast]	Anlaufstrom [Ampere]:	OK
P5 [RT] [200N Sindellast]	Gesamtlänge bei Schüttelprodukt f. Anlaufstrom:	OK



# Challenges for industrialisation: Piezo system

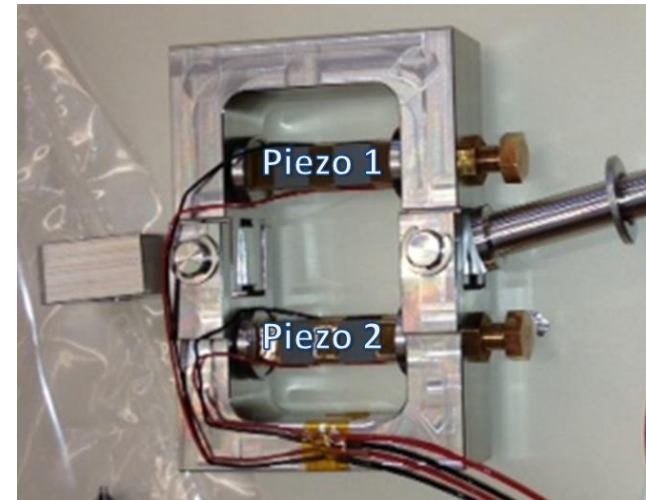
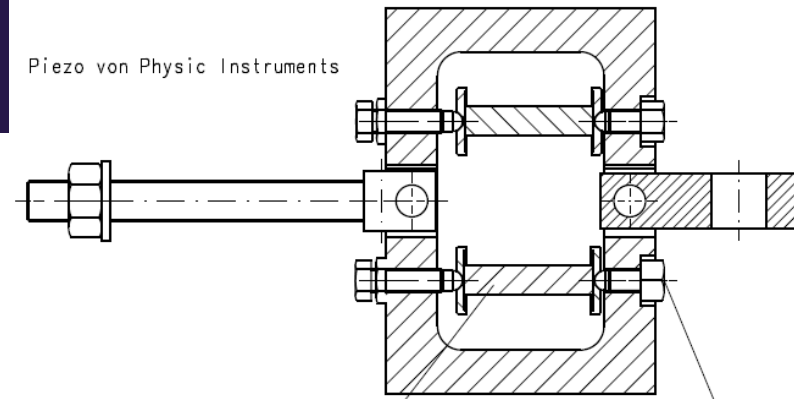


- DESY development with several iterations
  - Guaranteeing sufficient pre-load for piezos
  - Avoid loose piezos under all operation conditions
    - Change of pre-tuning of cavities
- Assembly 'hand-crafted' at DESY
- No burn-in tests
  - One special case of failure at initial operation suspected
    - Not fully conclusive data
- Therefore:
  - Require companies to
    - Further improve radiation resistance (ETFE cabling)
    - Respect vacuum compatibility
    - assemble piezo systems
      - More than buying piezos only
      - Use experience of piezo companies for assembly
    - perform burn-in test
      - Room-temperature considered sufficient
  - Implementation in series production

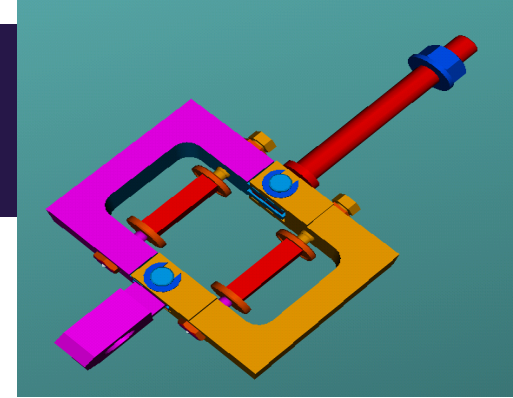


# Industrial fabrication of Piezo System

- Contract awarded to PI, Karlsruhe
  - PI Ceramics for Piezo elements
- Design improved of drawings
  - Avoid local stresses on piezos by optimising the plates used for pressing the piezo elements
    - Increases thickness
    - Definition of surface quality
  - Better fixation of the wiring



# Industrial fabrication of Piezo System



- Quality control
  - Burn-in test after assembly
    - ➔ DC test
      - 100 % of nominal voltage for 2 hours
    - ➔ AC test
      - Voltage: 100% of nominal piezo voltage
      - Pulse length: Sinusoidal Half Wave of 1000 Hz
      - Rep rate: 100 Hz
      - Number of Cycles: 1 Million
  - ➔ After the tests the following parameters should be measured
    - Capacitance
    - Stroke
    - Leakage current at nominal voltage
- QC protocols delivered into DESY EDMS system by company

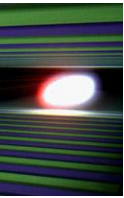
<b>EDMS-ID Piezo System</b>	D0000010137389
<b>Used EDMS-ID Piezo Fixture</b>	
<b>Number</b>	112025082
<b>Name</b>	FTA 206_8327_E_000-#0001
<b>Description</b>	
<b>Location</b>	Transportation
<b>Project</b>	XFEL_WP07_PI
<b>Team</b>	XFEL_WP07_PI Team
<b>TeamFolder</b>	Fabrication Documents

Verbaute Piezoaktuatoren	Batch Nr.
Nr. 1	12CEP0411461684
Nr. 2	12CEP0411431633

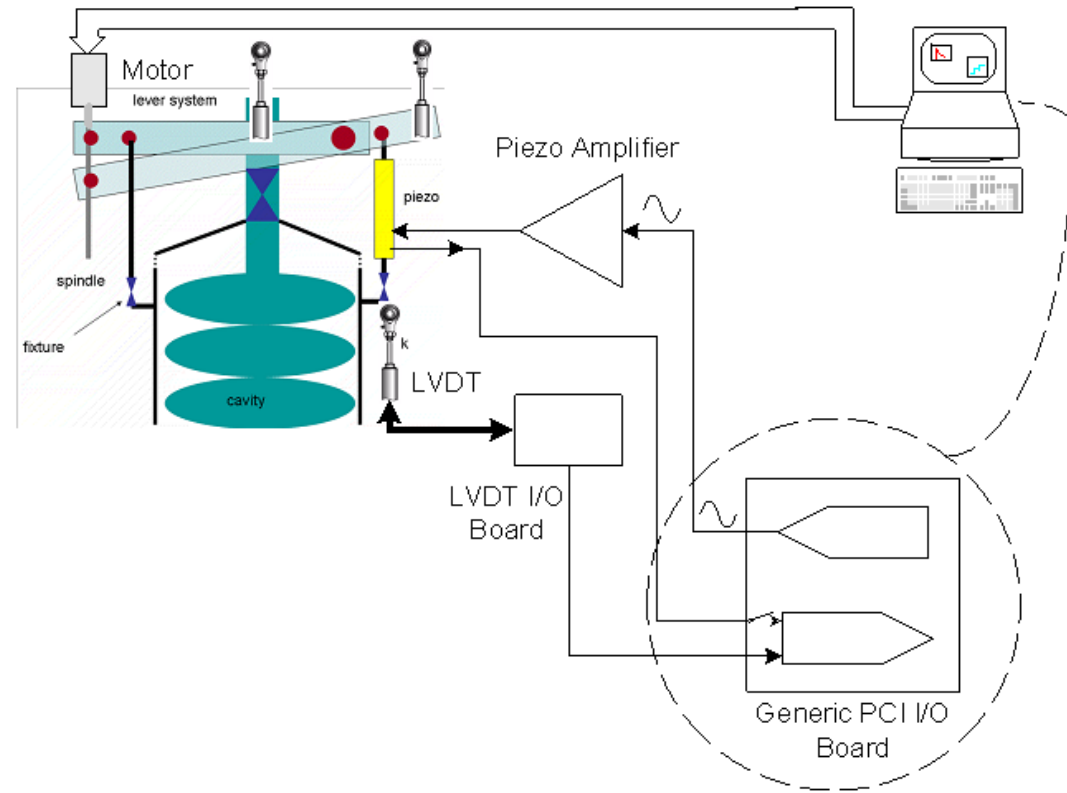
Spezifikationen		Toleranz
Kapazität	13µF	±20%
Leckstrom bei Nennspannung	8µA	max.
Auslenkung	t.b.d	±20%

Prüfung Ausgangstest	Beschreibung	Messergebnis
Piezo 1 vor Test	Kapazität	12,89
	Leckstrom bei Nennspannung	2,62
	Auslenkung	21,95
Piezo 1 nach Test	Kapazität	13,20
	Leckstrom bei Nennspannung	2,38
	Auslenkung	20,45
Piezo 2 vor Test	Kapazität	12,84
	Leckstrom bei Nennspannung	5,98
	Auslenkung	21,45
Piezo 2 nach Test	Kapazität	12,76
	Leckstrom bei Nennspannung	2,12
	Auslenkung	20,65

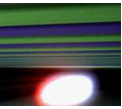
## Test Procedures Automation during Module Assembly



- Test both motor and piezo installation with an automated system
  - Proposal by INFN
  - Avoid polarity problems etc.
- Successfully implemented



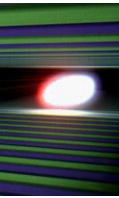
# Assembly Procedures



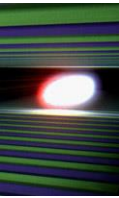
- Verification of current procedure
  - ➔ Very detailed
  - ➔ E.g. For training purposes
- Both Piezo and mechanical system
- Work of INFN with Module Assembly Team



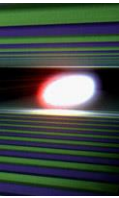
# Status of the System Components



- Mechanics:
  - Series fabrication ongoing.
  - Series piezo fixture delivery finished.
- Drive unit:
  - Documentation reports decided.
  - First units have FAT and been delivered to CEA and DESY.
  - Ramp up to series rate has been achieved.
- Piezo system:
  - Continuing tests of permanent FLASH setup.
  - Series production of fixtures ongoing.
- QC testing during module installation at Saclay (INFN contribution).
  - Series system completed (rack delivery).
- Fabrication of all tuner parts ongoing.
- Documentation in EDMS continues.

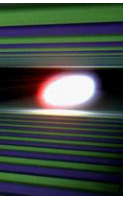


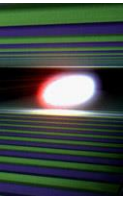
- Piezo systems ~400
  
- Normal tuners
  - Tuner mechanics ~ 300
  - Motors ~80
  
- Mirrored tuners
  - Tuner mechanics ~ 50
  - Motors ~12



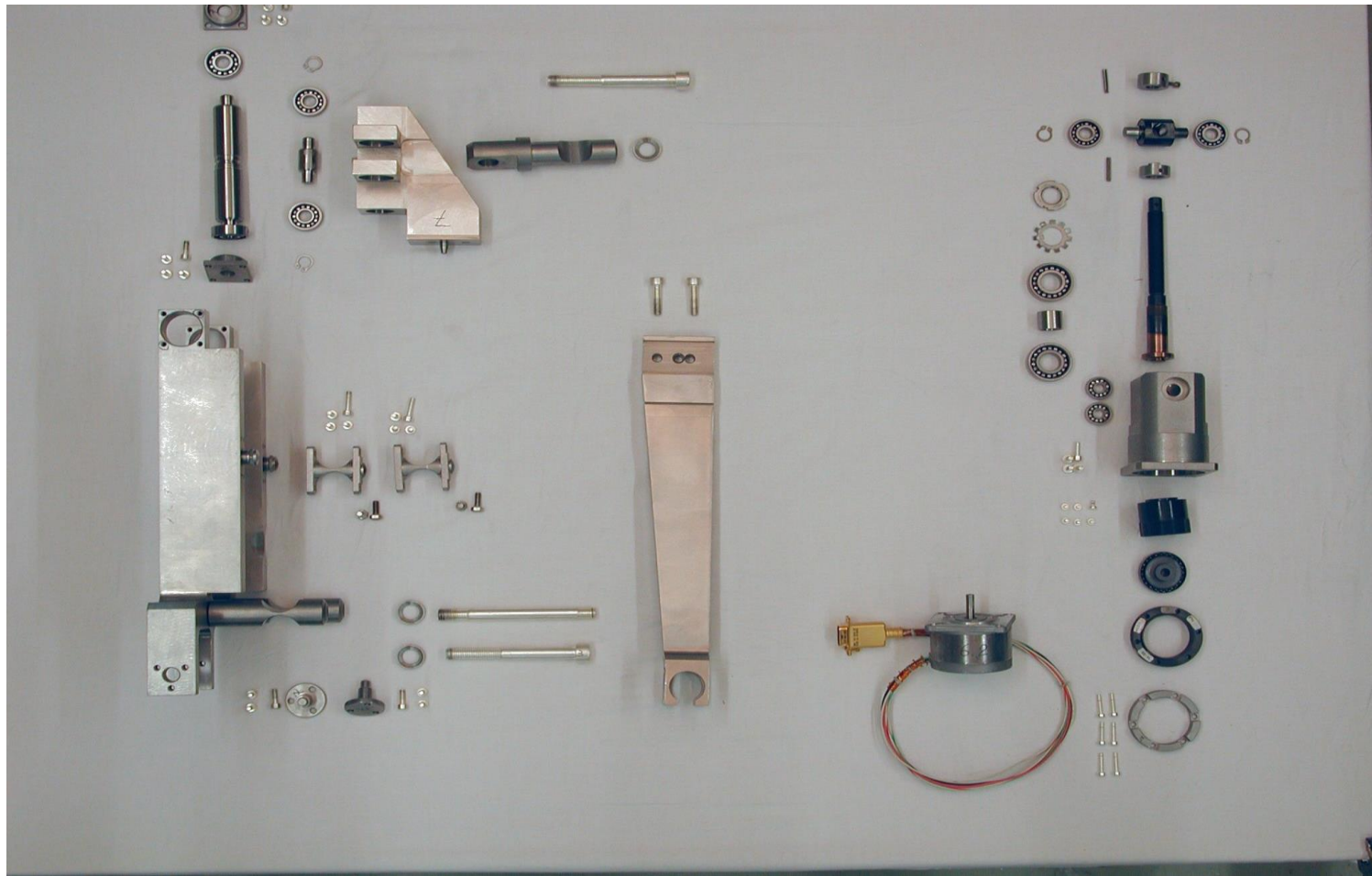
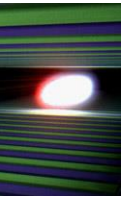
■ Thanks for your attention!

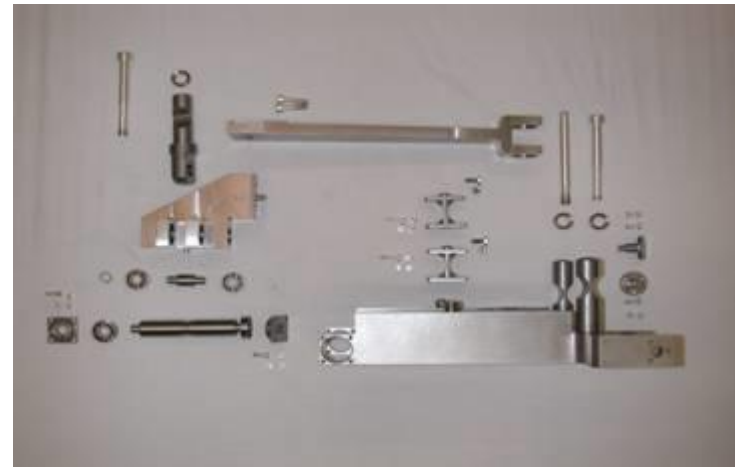
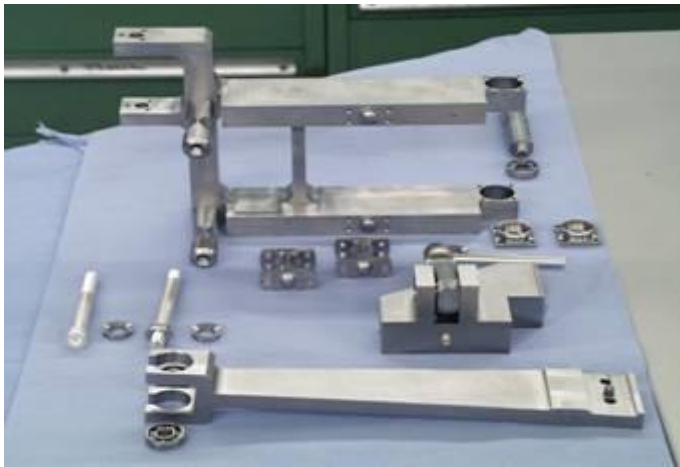
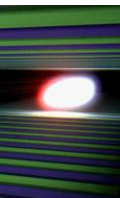




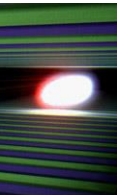


# Backup Slides

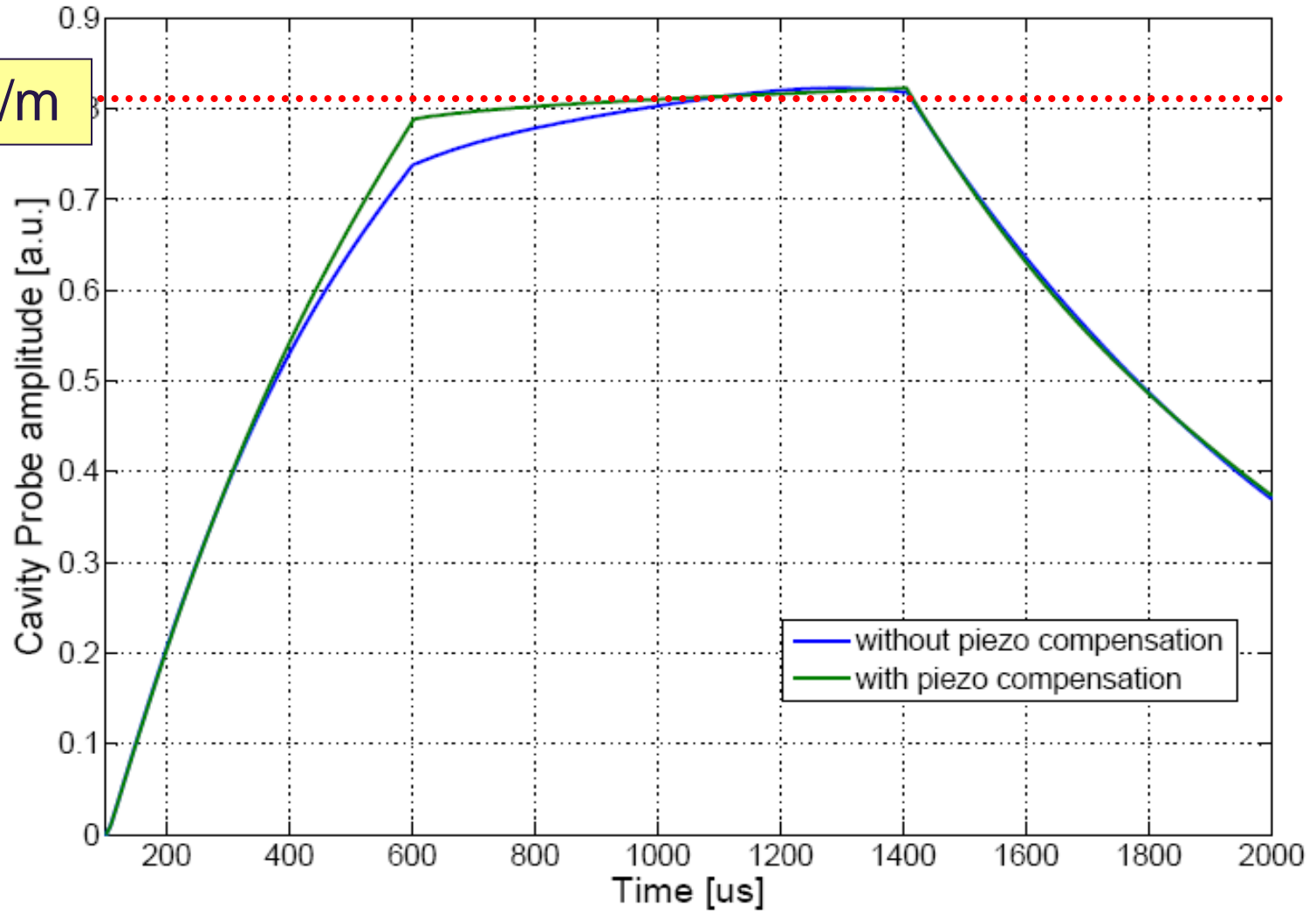




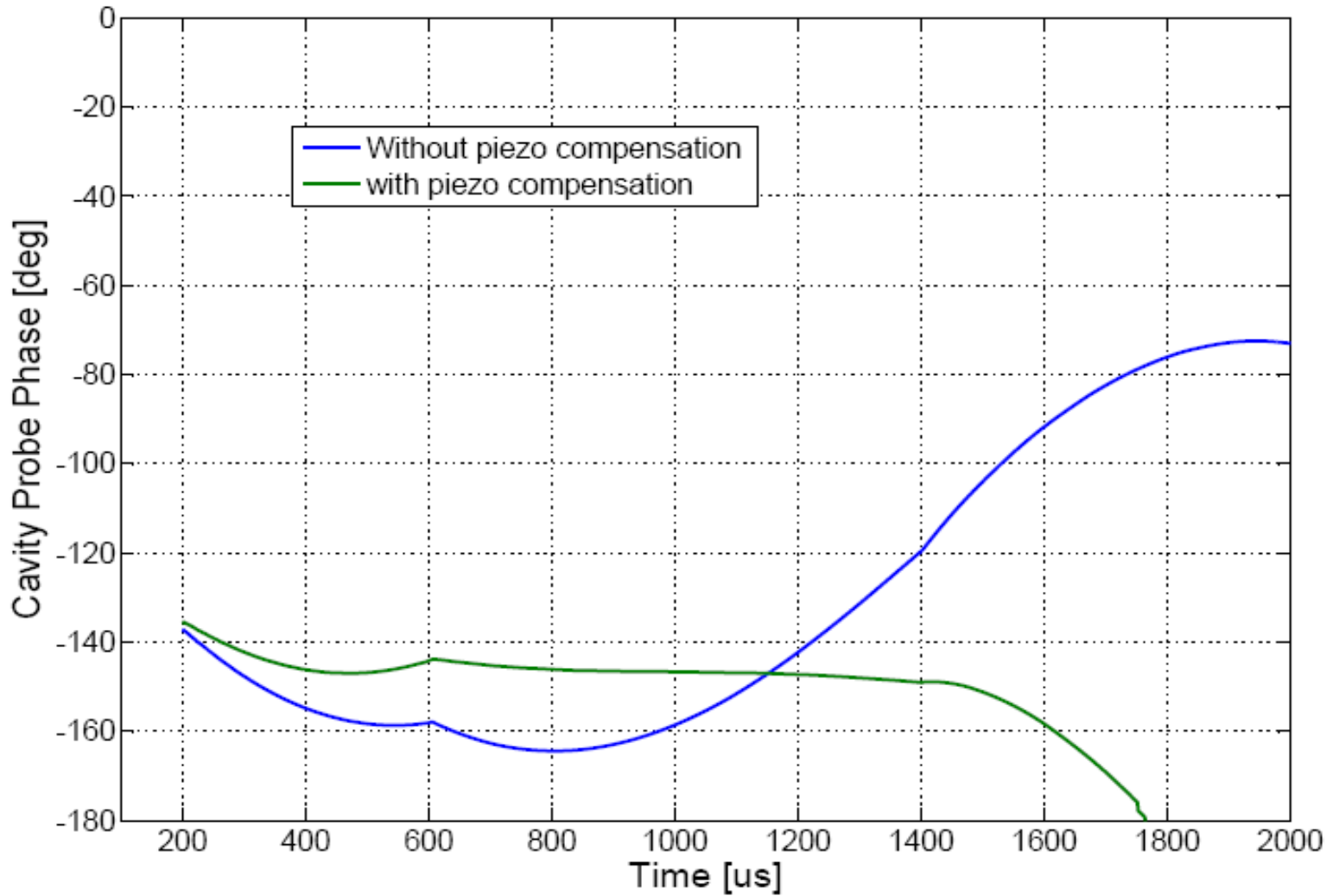
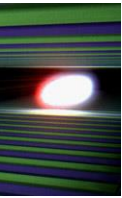
# Cavity 3: Gradient



35 MV/m



# Cavity 3: Phase



# Cavity 3: Detuning

