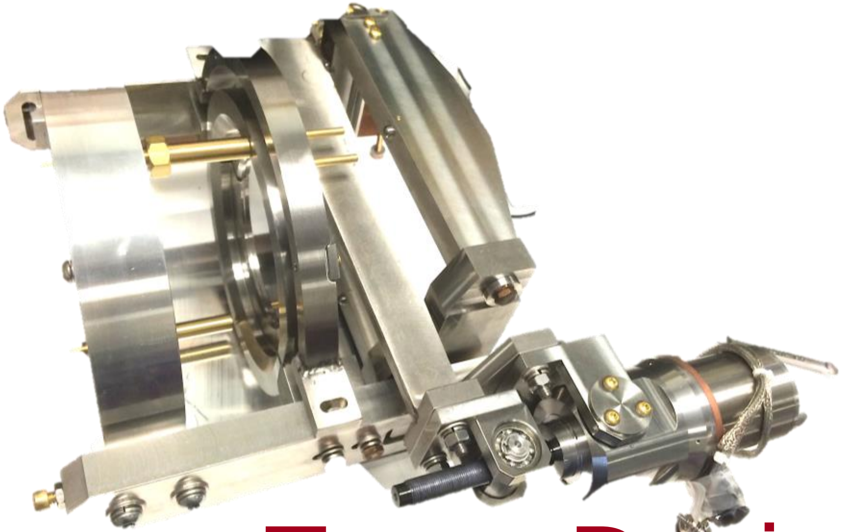
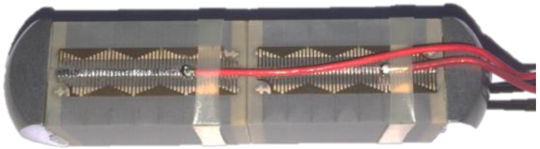




Tuner Design Update and Development at FNAL

Yuriy Pischalnikov

for FNAL's LCLS II Tuner Team

Mini-workshop SCRF cavity frequency tuners

CERN

Sept. 5, 2014

Outline

- Goals for LCLS II tuner design
- Functional/Technical specs
- Incorporation of SACLAY I (XFEL) Tuner design ideas into LCLS II Tuner
- Tuner Schematics & Design
- Simulation of the proposed design
- Selection of Electromechanical actuator/ lifetime test of actuators
- Fast Tuner Design/ differences between XFEL and LCLS II Piezo Tuners
- Collaboration with PI to build custom piezo-tuner
- Status of Tuner Prototype production & testing
- R&D program at FNAL to study Piezo Tuner reliability

Goals

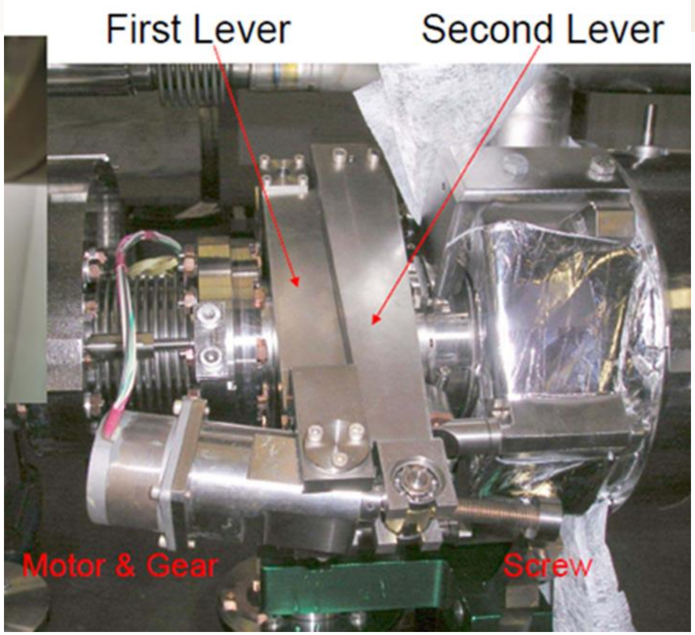
- *To design tuner which will fit to existing inventory of cavities at FNAL. ..”<u>short-short”</u> (cavity built for slim blade tuner for CM3/4/5…).*

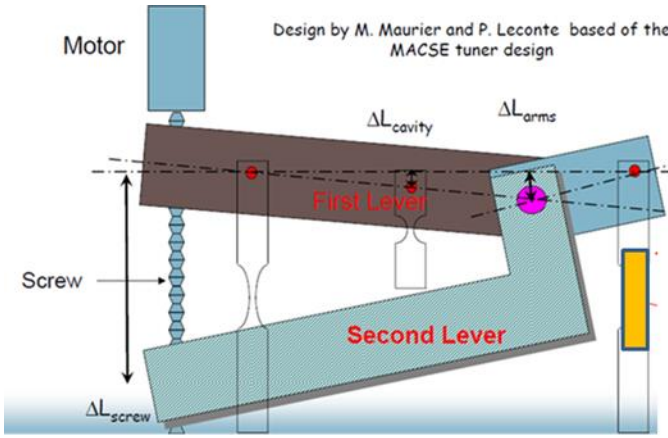
  SACLAY-I (XFEL) tuner designed for <u>“short-long”</u> cavity;
- *Active tuner components (electromechanical actuator& piezo-stack) can be replaceable through special port;*
- **High reliability of tuner components (electromechanical actuator and piezo-actuator);**
- **Cavity has narrow bandwidth (~30Hz) → tight requirements for slow/coarse & fast/fine tuning resolution;**

Tuner Functional/Technical Requirements Specifications

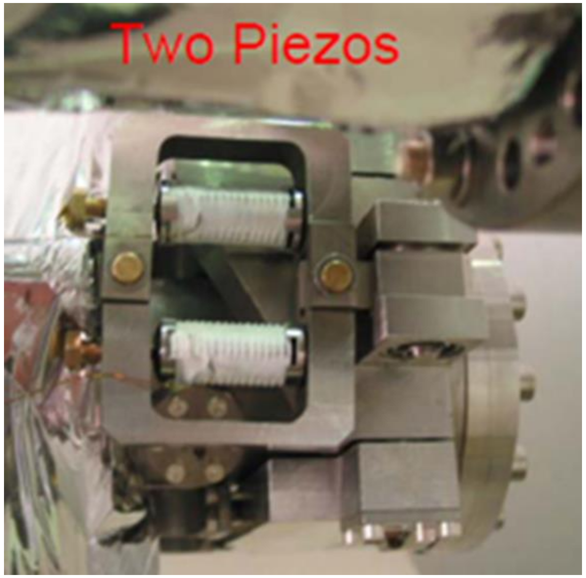
	LCLS-II	XFEL
Parameters	*Value*	*Value*
Cavity Frequency	1.3GHz	1.3GHz
Cavity bandwidth	30Hz	200Hz
Cavity elongation tuning	340Hz/um	340Hz/um
Cavity Spring Constant	3N/um	3N/um
Slow Tuner freq. range (expected)	**250kHz**	**200kHz**
Slow Tuner freq. range (max)	***420kHz***	***600kHz***
Slow Tuner cavity displament(exp./max)	740/1300um	1900um
Slow/Coarse tuning sensitivity	1-2 Hz/step	1Hz/step
Fast Tuner cavity freq. range	**1KHz**	**1KHz**
Fast Tuner dimentional range	3um	3um
Fast Tuner tuning resolution	**1Hz**	**10-20Hz**
Fast Tuner stroke resolution	3nm	30-60nm
Fast Tuner response bandwidth	5kHz	1kHz
Min. tuner stiffness	**30N/um**	**20N/um**
Min. tuner mechanical resonance	5kHz	5kHz
Tuner operating condition	insulated vacuum T=20-60K	insulated vacuum T=20-60K
Slow Tuner / electromechanical lifetime (20years)	1000 spindle rotation	1000 spindle rotation

SACLAY I/XFEL Tuner





Fast/Fine Tuner-
<u>Double C-clamp with 2 piezo</u>



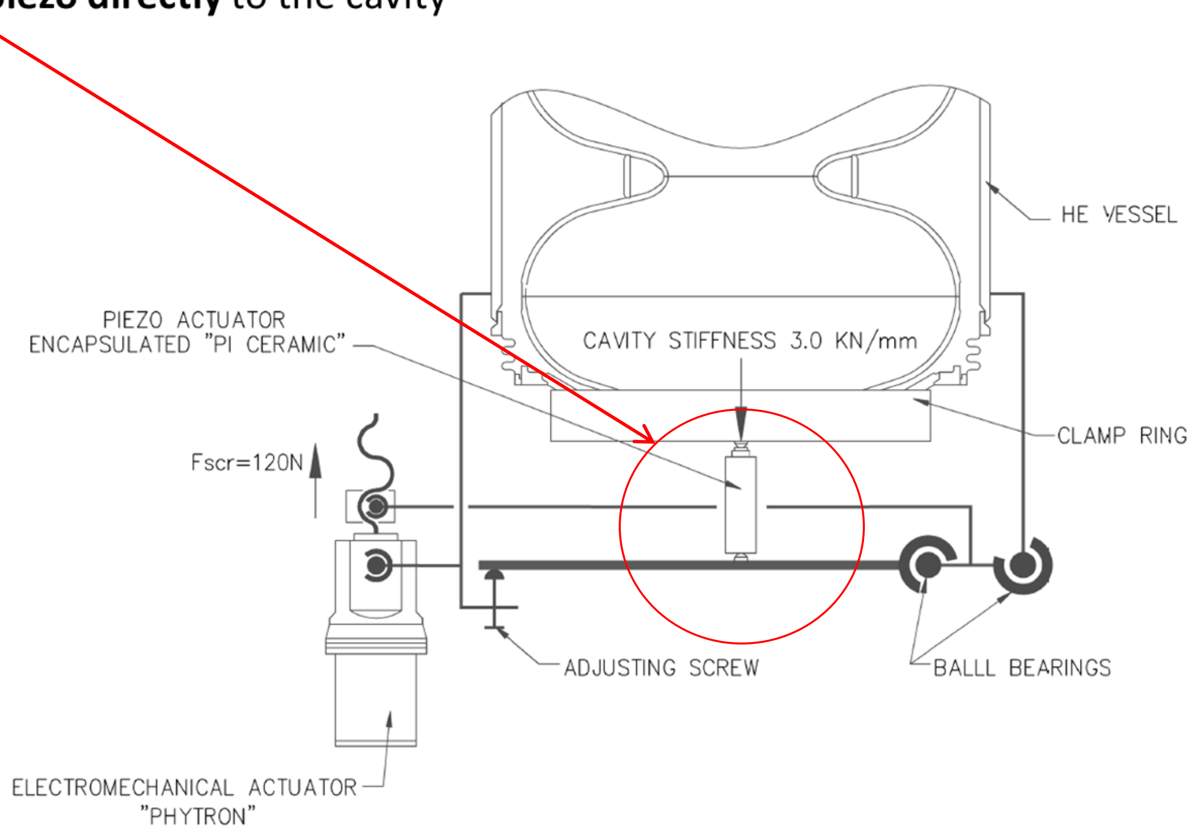
Double Lever (1:17)
<u>Real ratio is 1:25</u>

XFEL Fine/fast tuning:
Translation of the piezo stroke through flex joints/pins
But XFEL reqs → 10-20Hz (30-60nm)

Proposed LCLS II Tuner Schematics

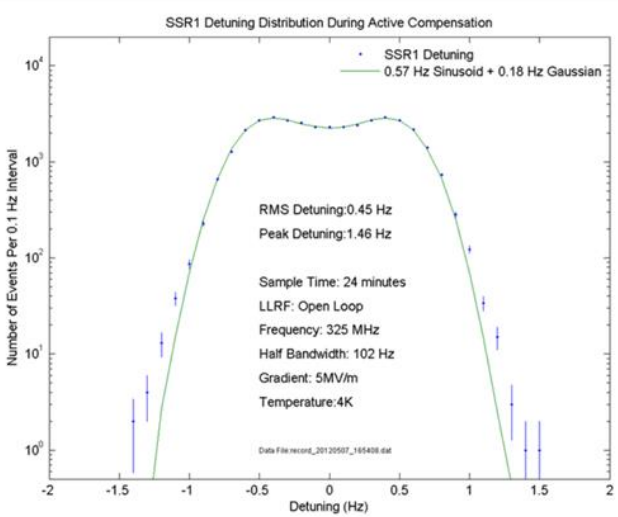
- Slow/Coarse Tuner is double lever tuner (close to design of the SACLAY 1)
- Coarse Tuner ratio 1/20 (Saclay 1 ~ 1/17)
- Fast Tuner - two piezo installed close to flange of cavity /translation of the **stroke from piezo directly** to the cavity

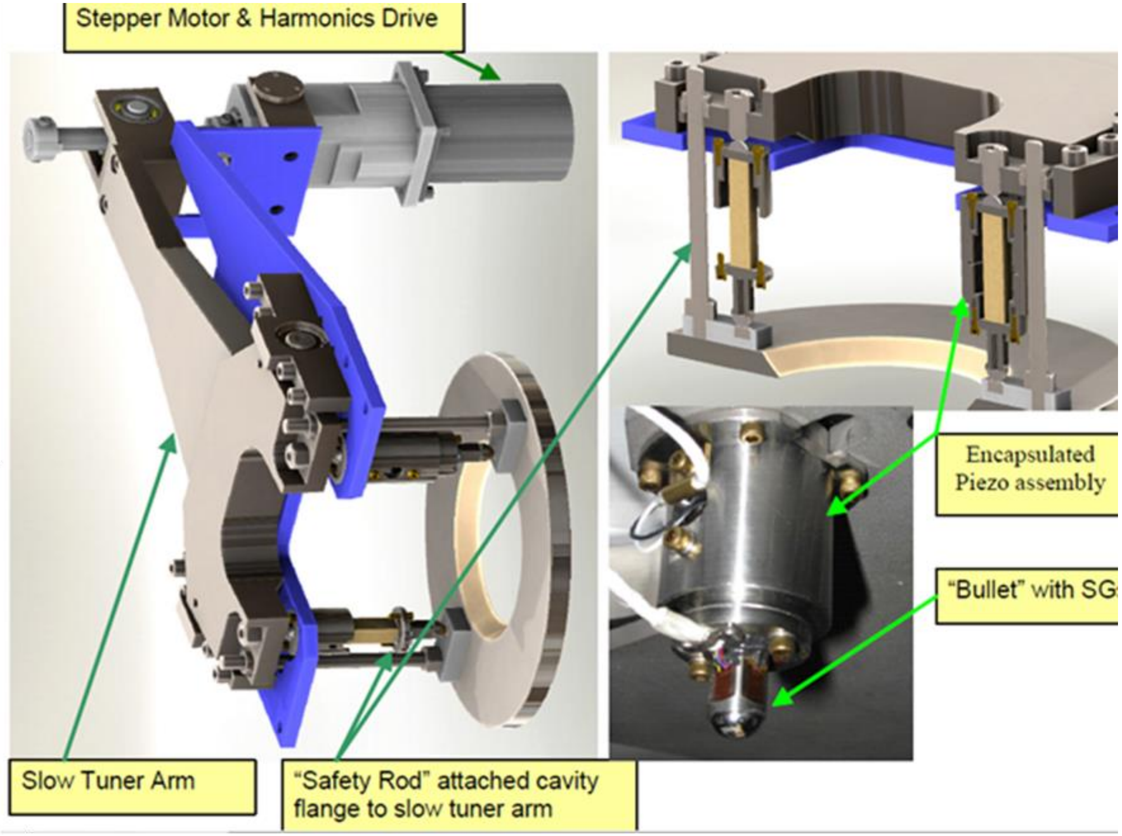
PI Ceramics experts expressed concerns: it will be challenge to reach 3 nm resolution when stroke translated through flex joints/pins



LCLS-II CAVITY SIDE TUNER SCHEMATIC

Translation of the sub-nm stroke from piezo to cavity (direct translation – SSR1 Experience)

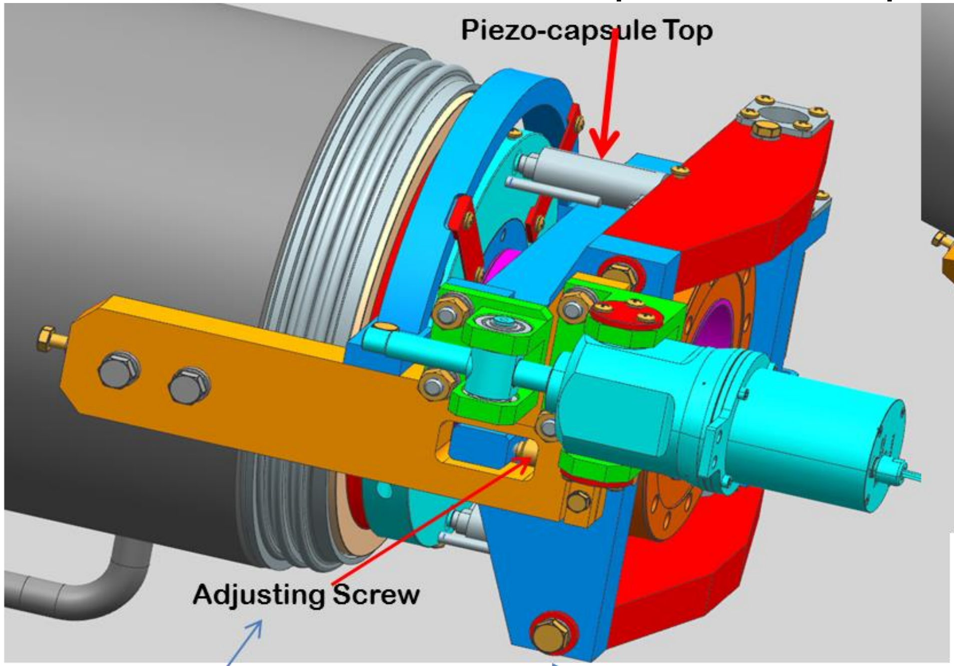


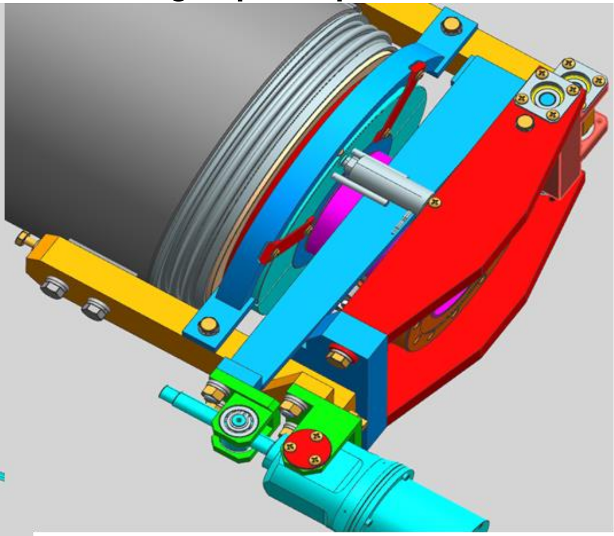


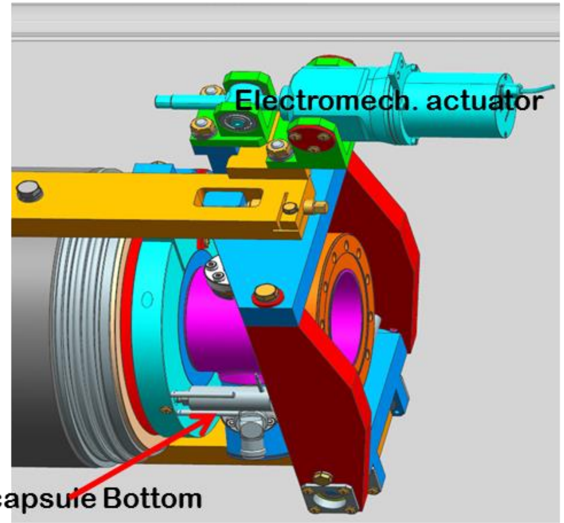
σ=1Hz → piezo tuning resolution ~ 2nm

LCLS II Tuner *(designer Evgueniy Borissov)*

Electromechanical actuator & piezo can to be replaced through special port



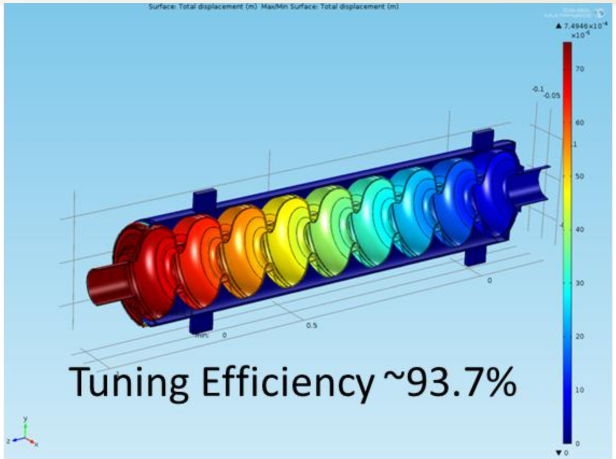


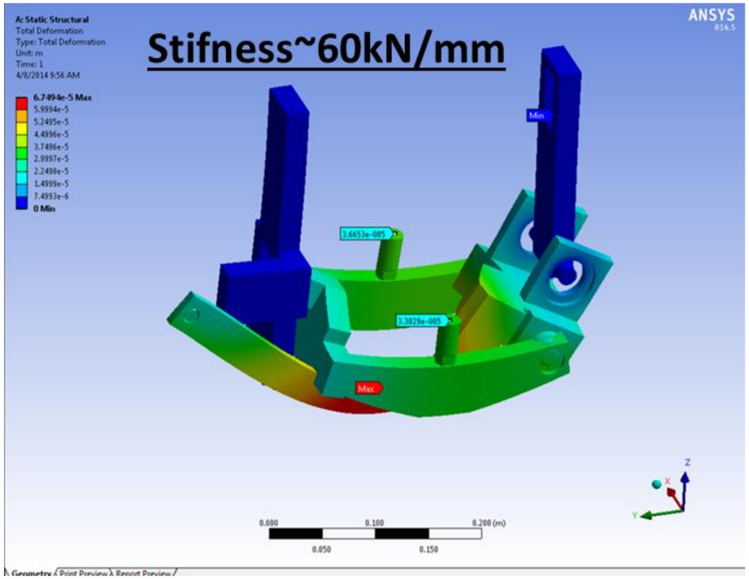


Adjusting Screw to unload piezo-capsule for replacement (in case of failure)… capsule can be replaced through special port

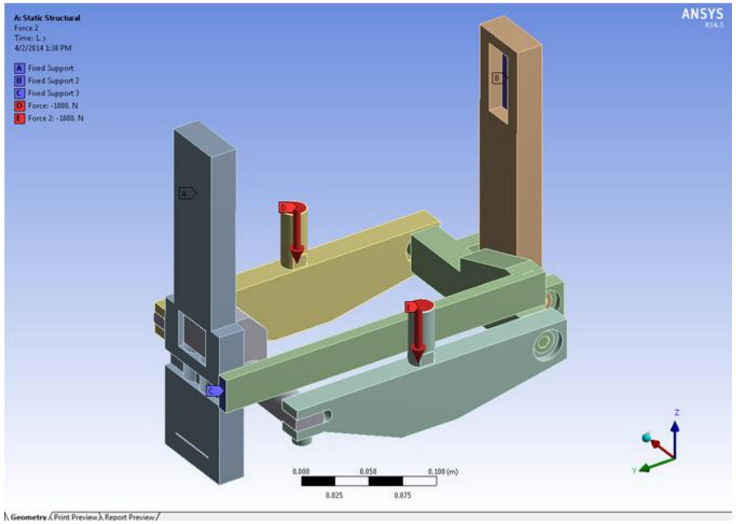
Tuning mechanism to uniformly preload piezo-capsule during initial assembly.

Tuner Simulation

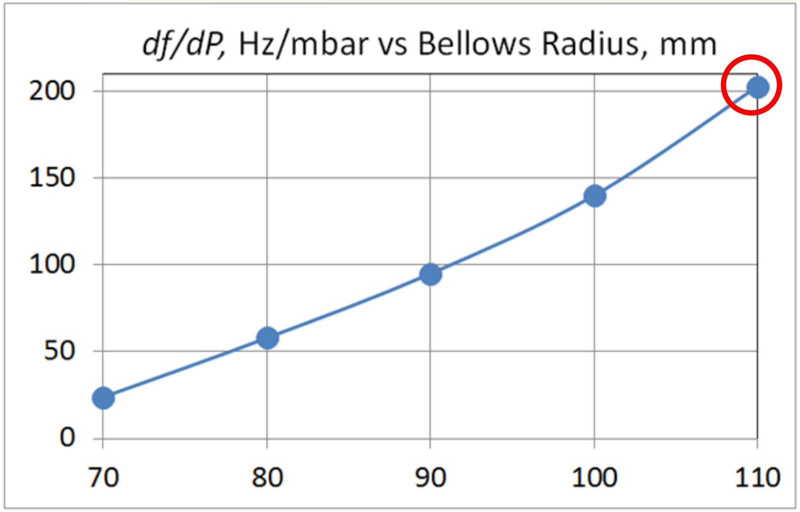




SIMPLIFIED MODEL OF LEVER TUNER

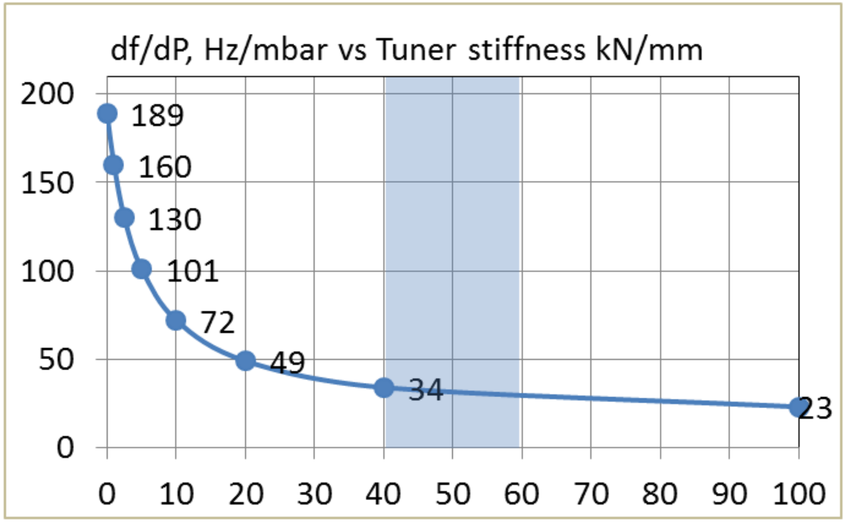


Cavity/He Vessel/Tuner pressure sensitivity



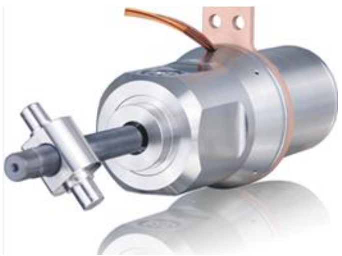
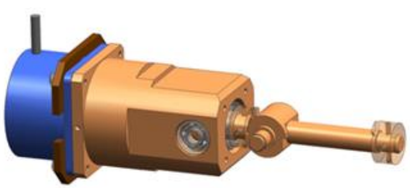
df/dP as a Function of Bellows Radius for Cavity Alone (unconstrained)

df/dP as a Function of Tuner Stiffness



The sensitivity of the assembly should be less than 34 Hz/Torr.

Electro-mechanical Actuator (stepper motor/gear box/spindle&nut) (for coarse tuning)

Picture	Name	Motor	Gear Box	Spindle/Nut	Forces	Longevity tested
	LCLS II	Phytron 1.2A	planetary gear (ration 1:50)	Titanium & SS M12*1	+/-1300N	tested in ins. vacuum at HTS for 5000 turns **(5 XFEL lifetimes).** In the force range +/-1500N. Motor run with current 0.7A
	XFEL	Sanyo	Harmonics Drive (ration 1:100)	CuBe (safety issues) M12*1	400N	tested in insulated vacuum at HTS for 3000 turns (**3 XFEL lifetimes**).

Electromechanical Actuator Lifetime

Electromechanical Actuator:

- Stepper Motor
- Reduction Gearbox
- Rotational-to-Linear Conversion (Spindle &Nut)

Cold vacuum is difficult environment for electromechanical systems

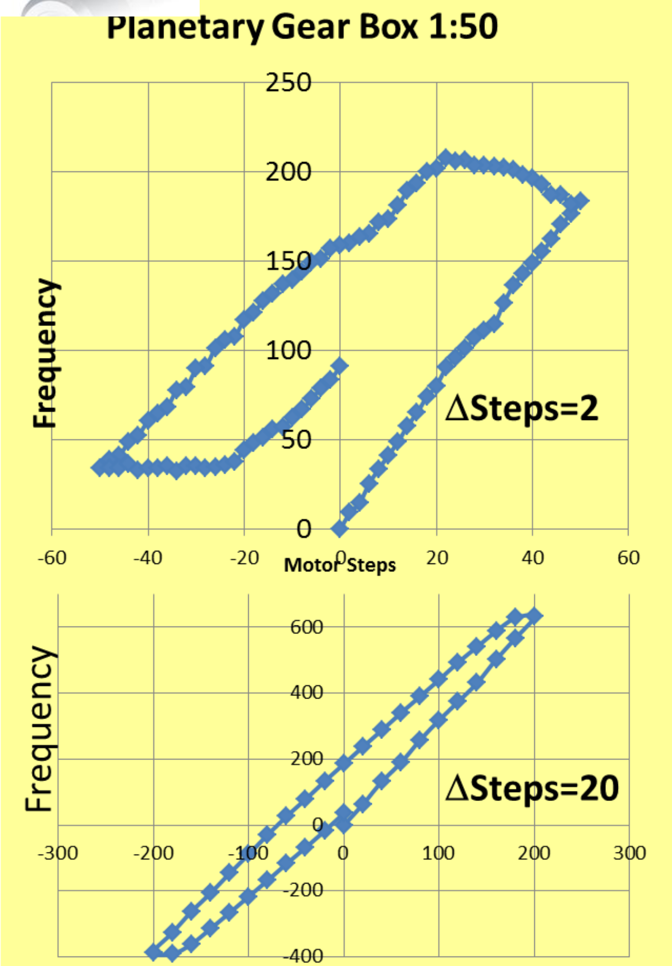
Every component is a potential point of failure, piezo, stepper, gearbox, linkage…

<u>Multiple Failure of harmonics drive and Shaft at SNS, CM2, S1G</u>

5000 spindle Rotations
Phytron Ti spindle

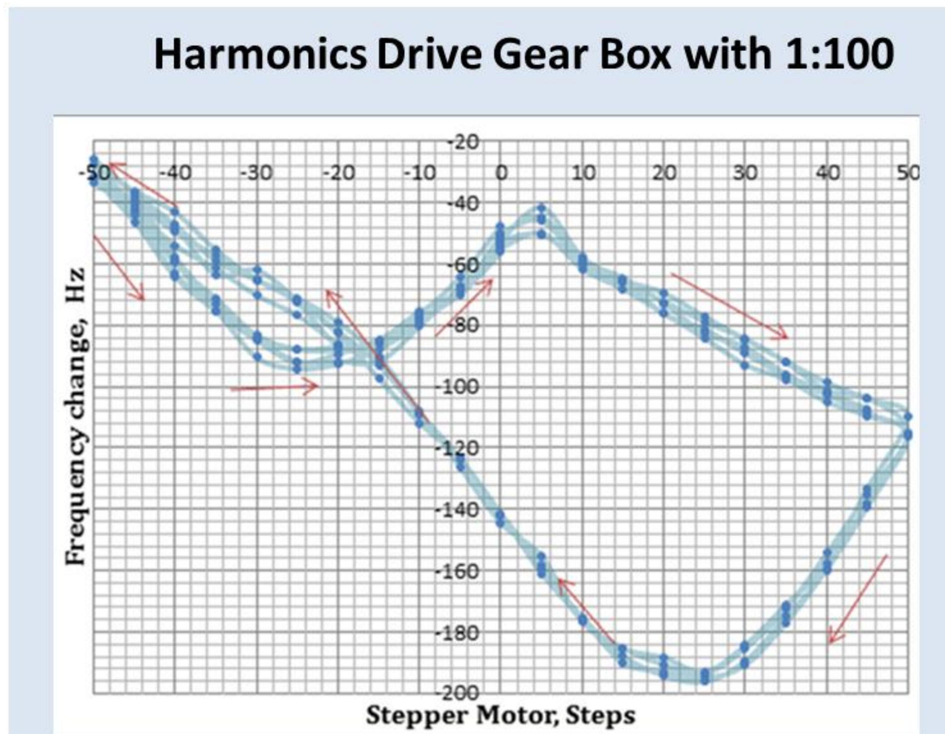
Slow (coarse) Tuner Hysteresis

Phytron LCLS-II actuator



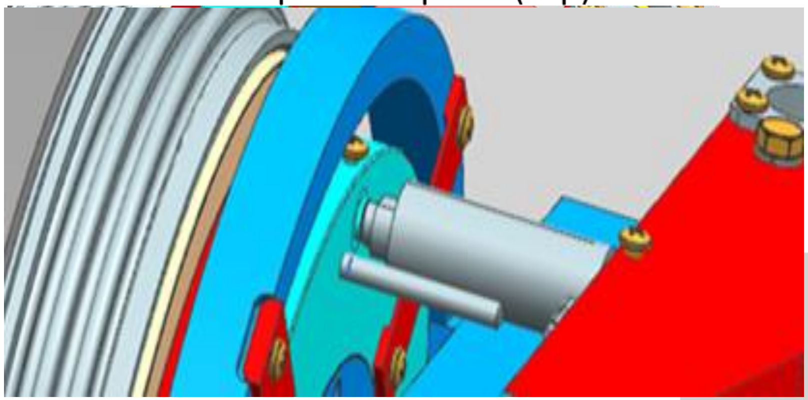
Measurements at HTS
1.3GHz 9-cell cavity equipped Blade Tuner with 2 different type of actuators

Harmonics Drive&CuBe spindle & Phytron stepper motor

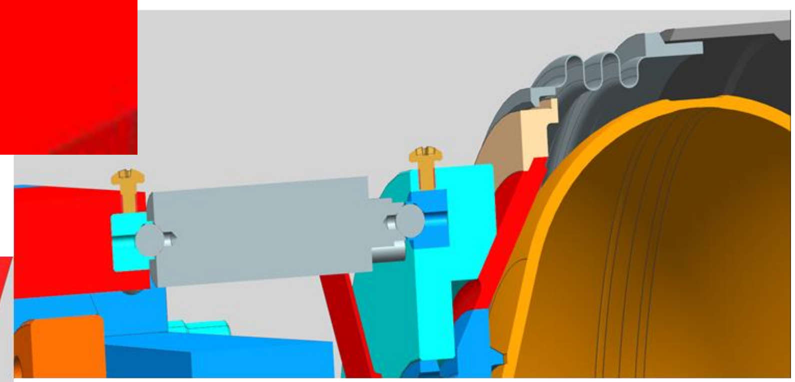


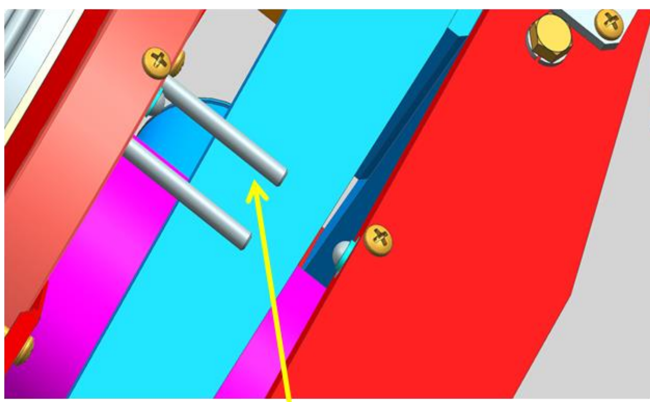
Details of Fast Tuner Design

Encapsulated piezo (top)

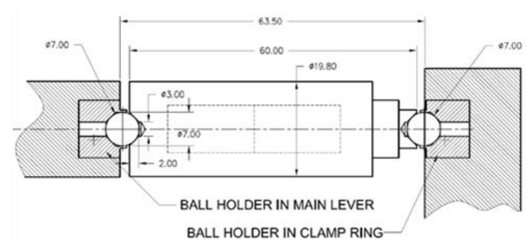


Piezo capsule can be replaced through special port



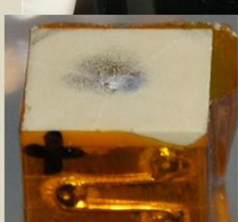


Horizontal support rods – to support piezo-capsules in the process of installation/replacement

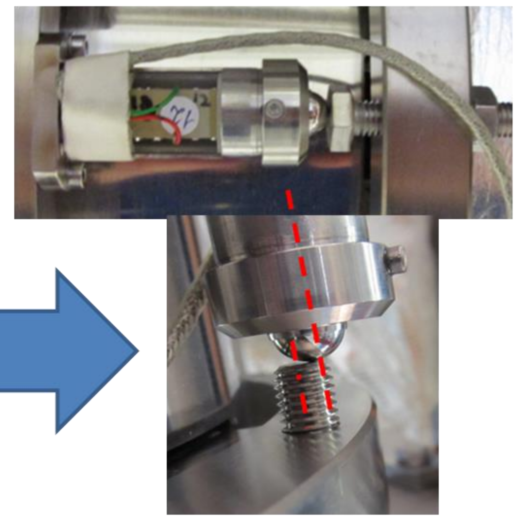


Details of Fast Tuner Design/ Shearing Forces & piezo longevity (CM2 & S1Global experience)

Shearing Forces
applied to piezostack

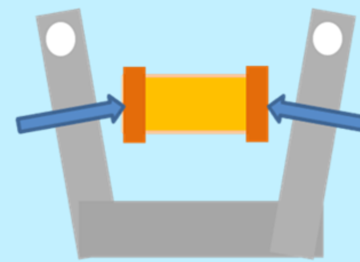


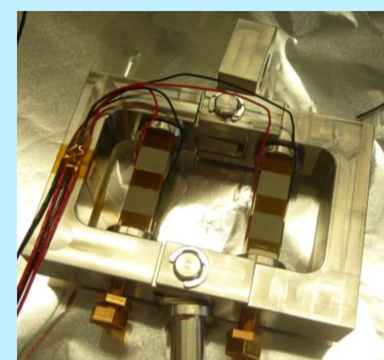
Modification for CM2 (piezo-capsulation)



XFEL Double C-clamp fast tuner → potential for build-up of shearing forces on piezo during assembly (pre-loading) and during cavity tuning with slow tuner

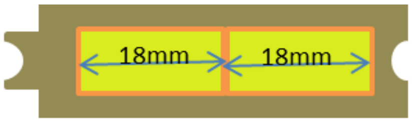
Only ½ of piezo stroke translated to cavity.



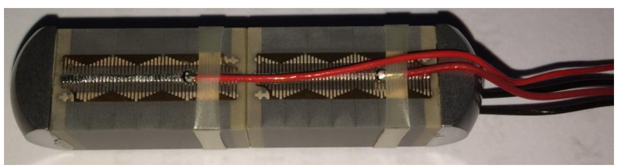


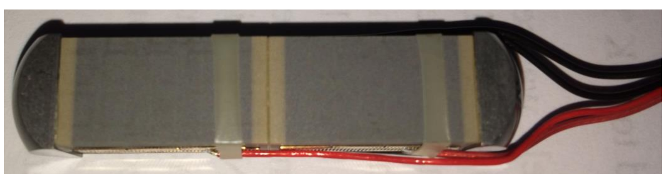
Encapsulated piezo for LCLS II Tuner/ Collaboration with PI

Capsulation of the piezo (custom design by PI Ceramics engineers based on FNAL's specs)to avoid any shearing forces on the piezo & set piezo preload in specified range (at 20K)

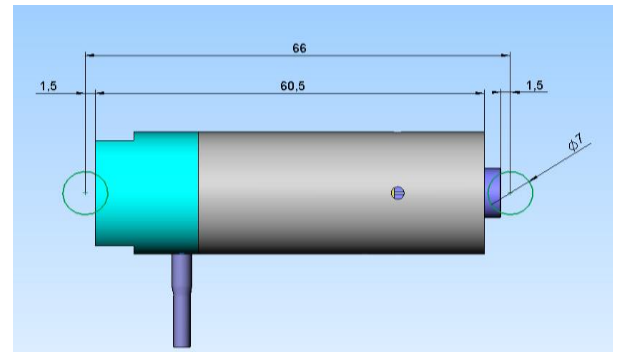


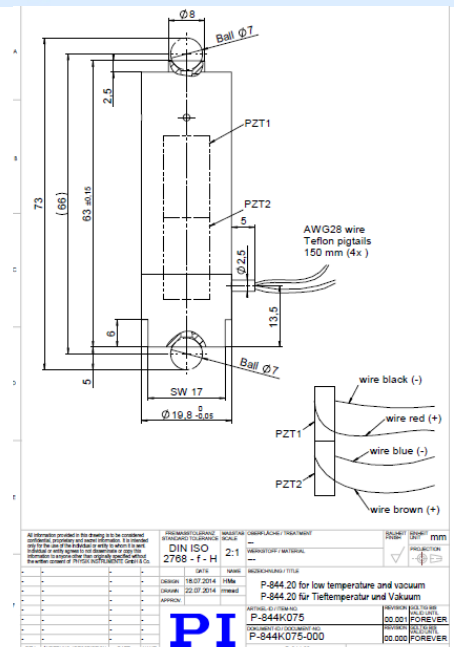
Two 10810*18mm piezo (glued together).
Run both piezo simultaneously



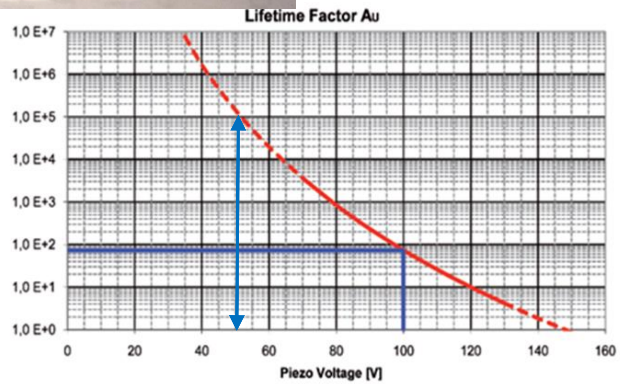


P-844K075



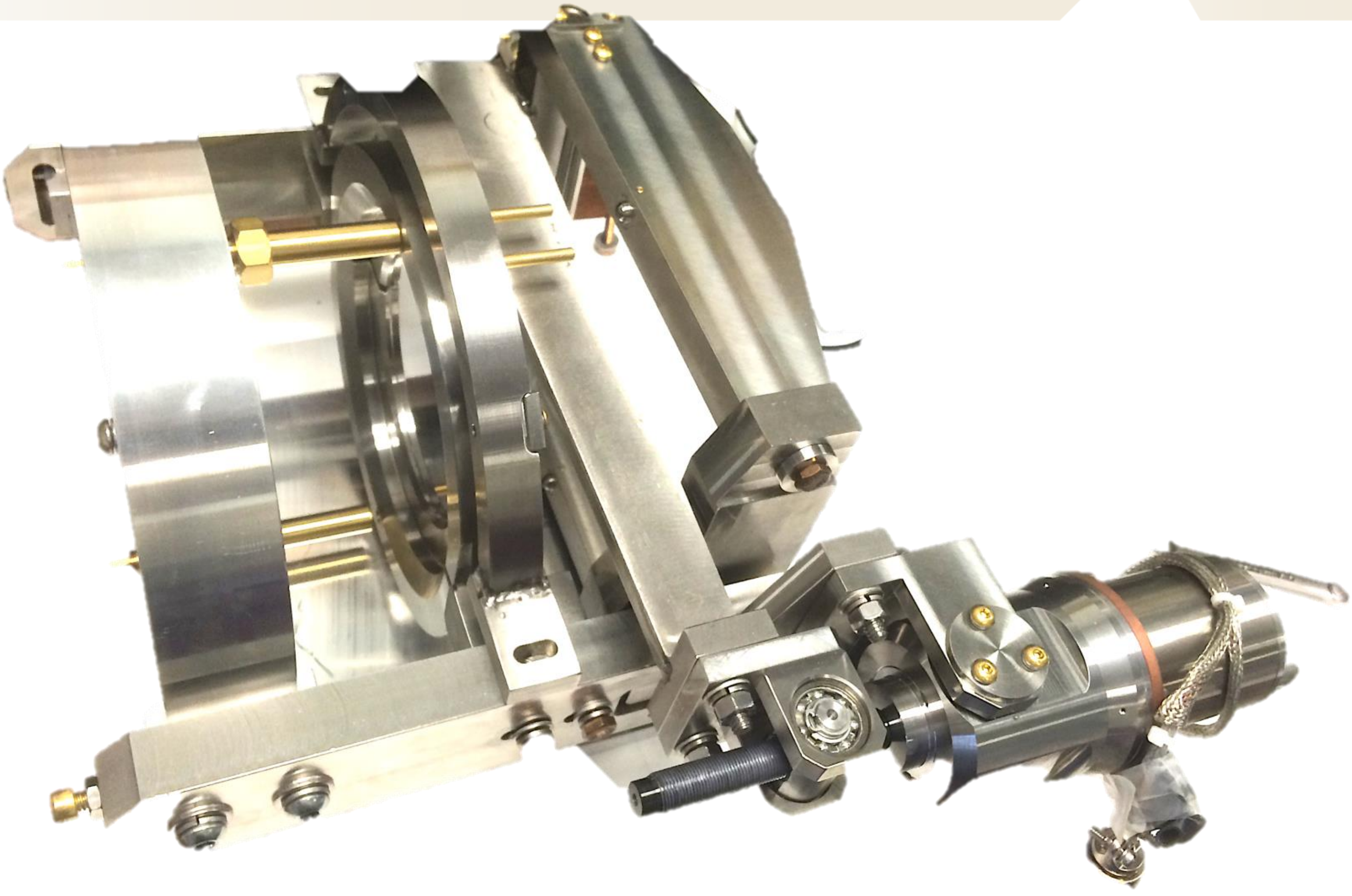


100% of piezo stroke translated to the cavity. Decrease voltage in 2 times will increase piezo lifetime in 1000times.

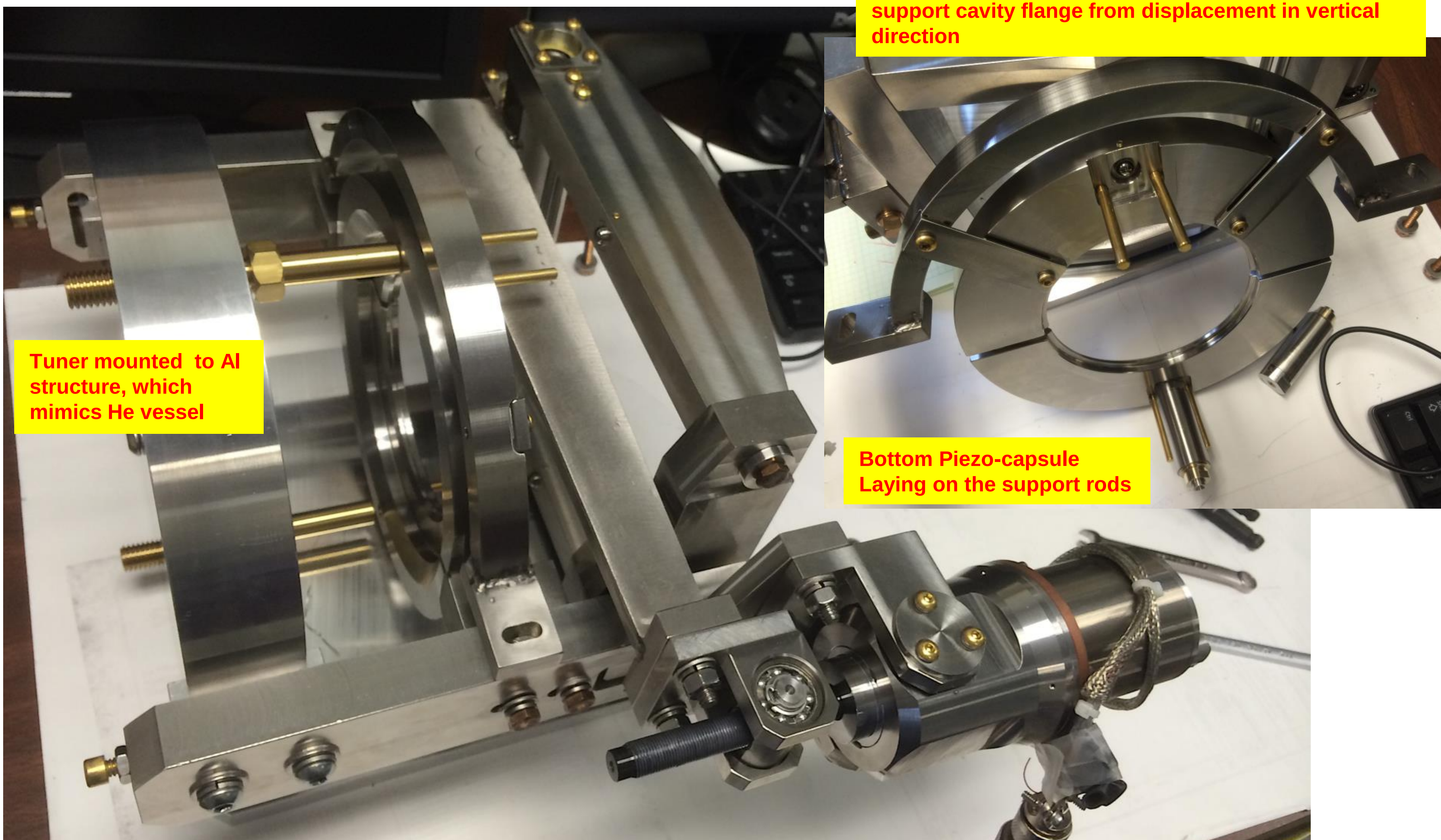


Yu.Pischalnikov, CERN Sept. 5, 2014

First LCLS II Tuner assembled at FNAL last week



First Tuner assembly (design details)

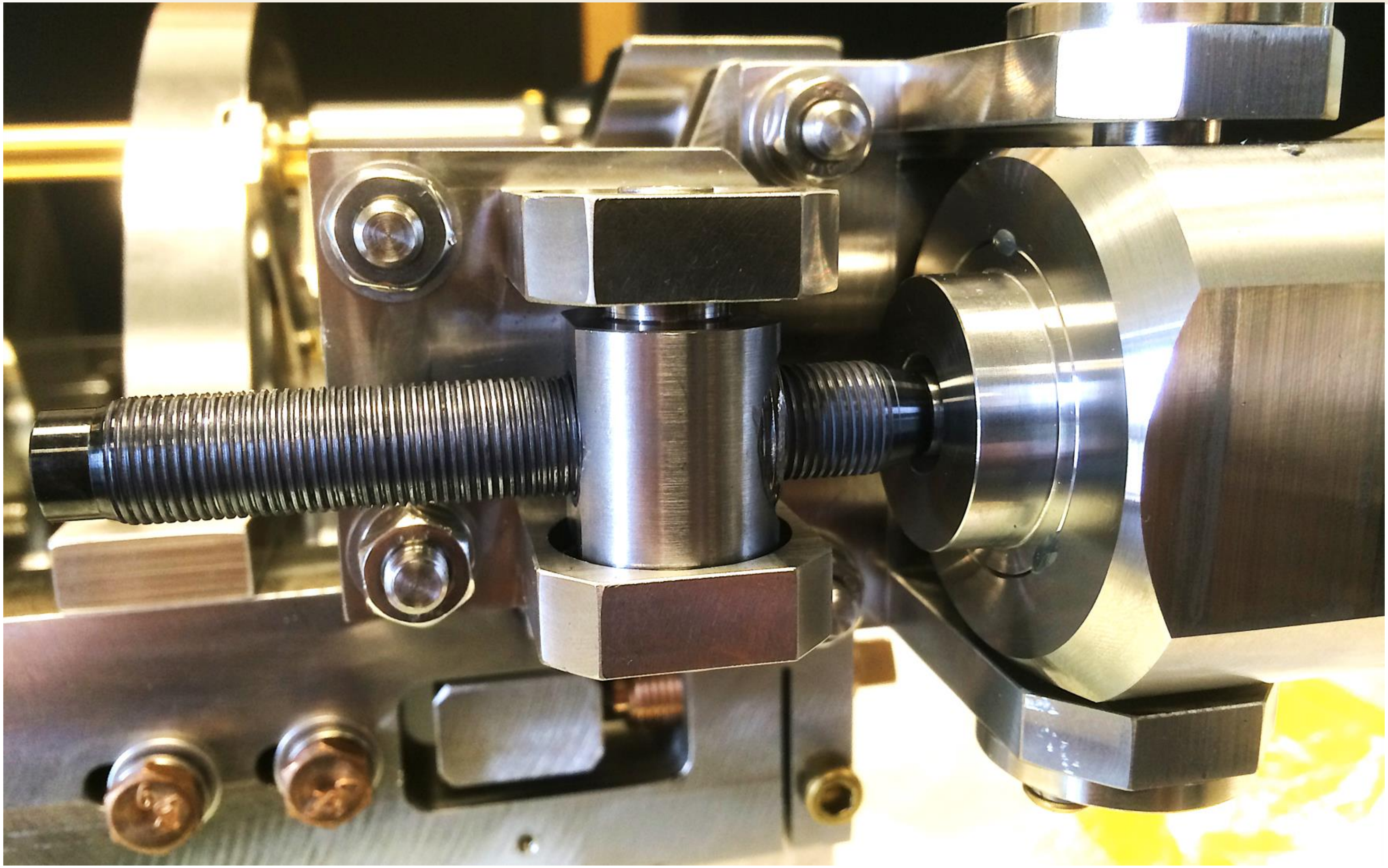


Tuner mounted to Al structure, which mimics He vessel

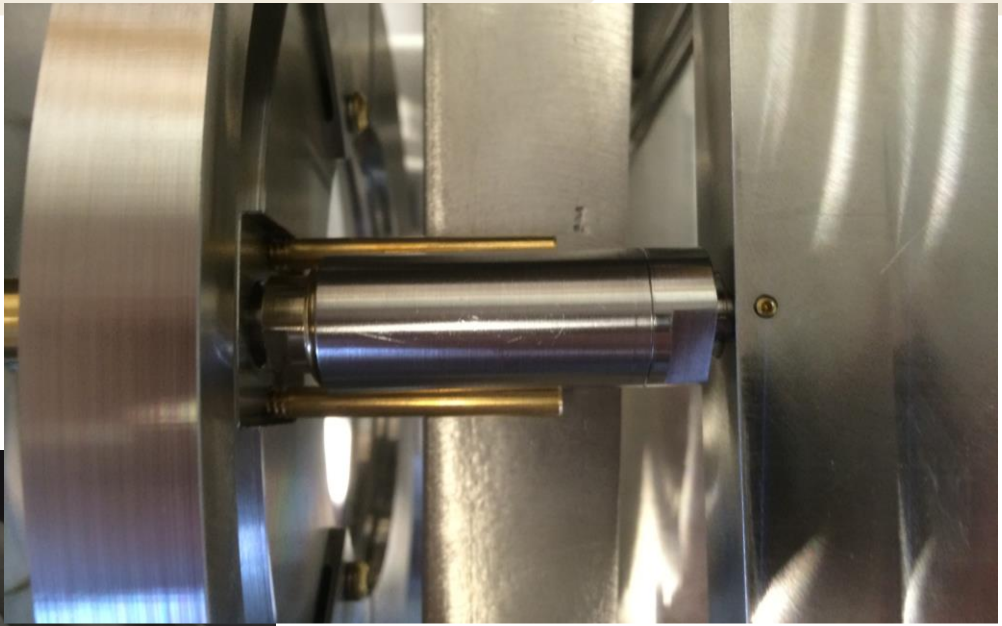
Clamp-ring- to mount on the cavity flange ; ½ ring to support cavity flange from displacement in vertical direction

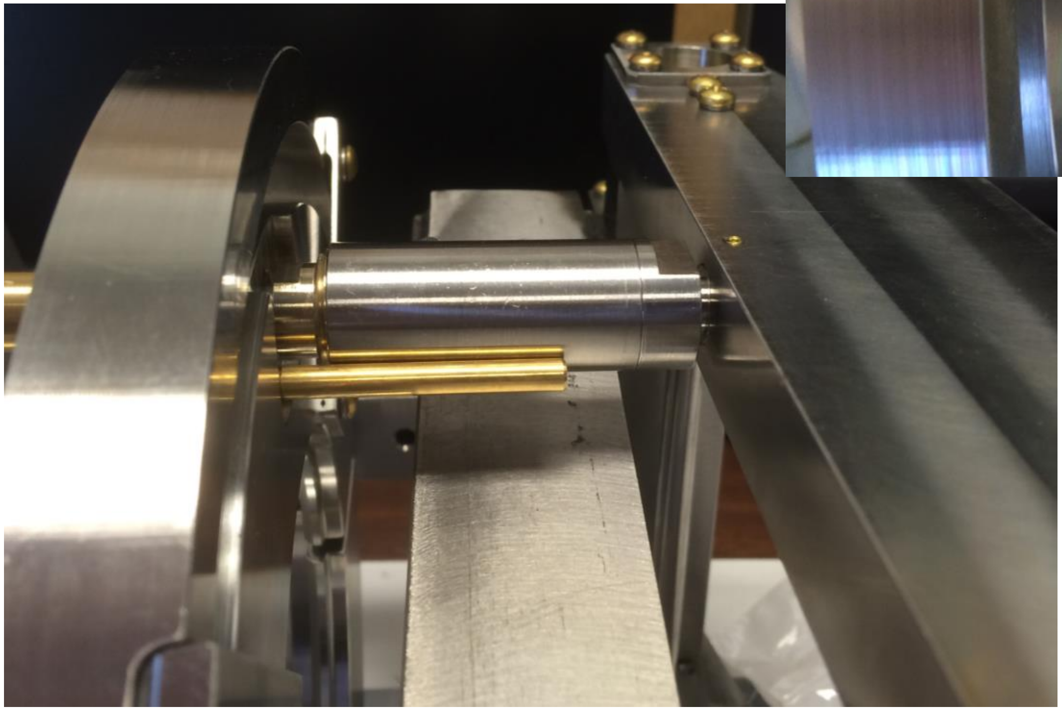
Bottom Piezo-capsule Laying on the support rods

Electromechanical actuator mounted on the tuner with the 4 nuts. Can be removed (and installed back) through special port.

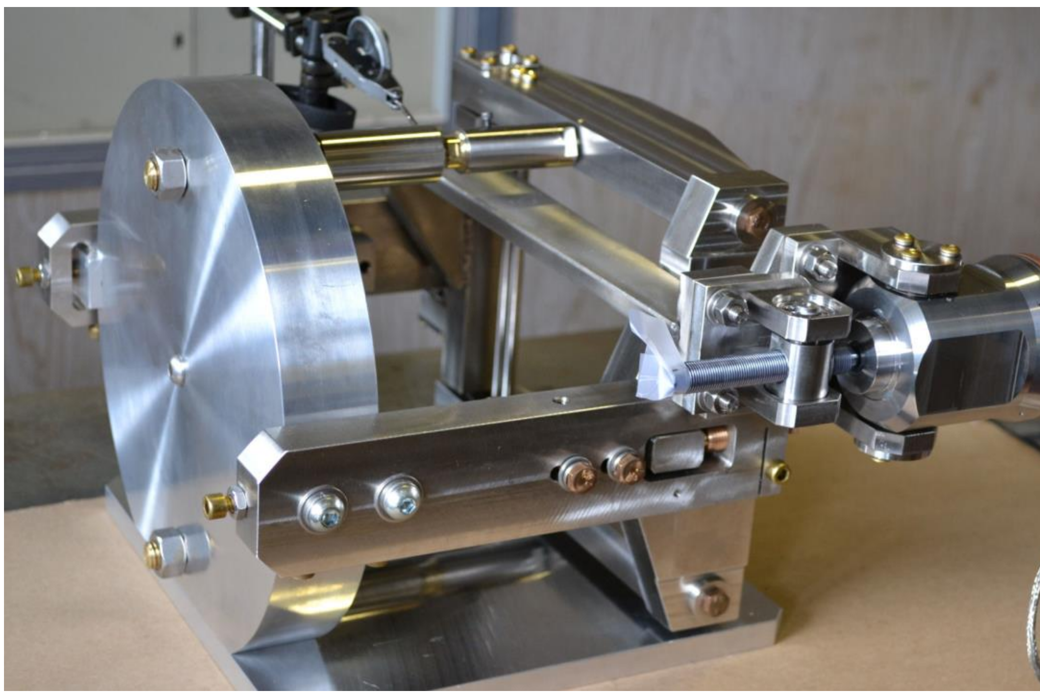


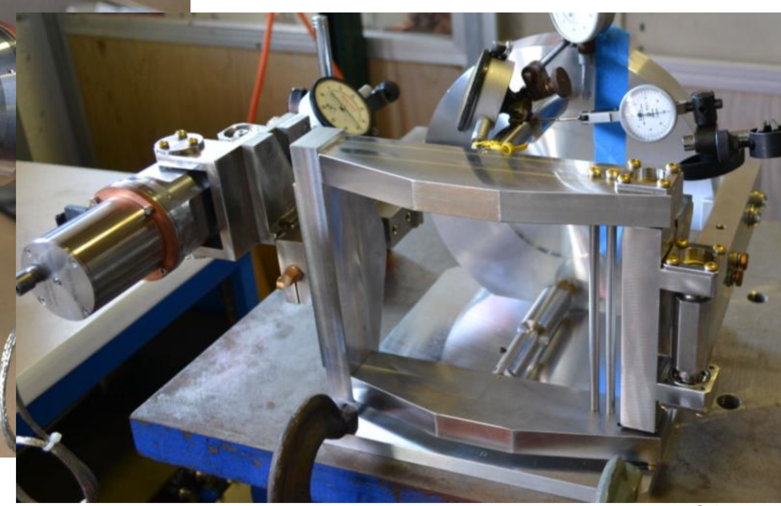
Piezo-capsule (top). Installed between main arm of slow tuner and flange mounted on then cavity.



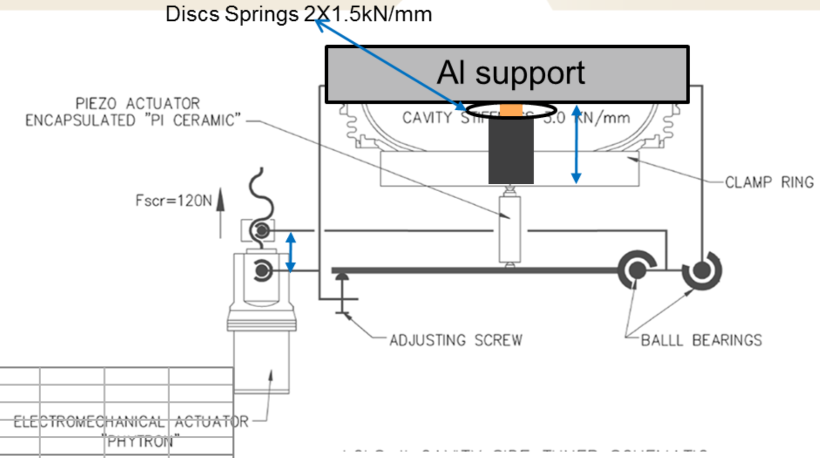


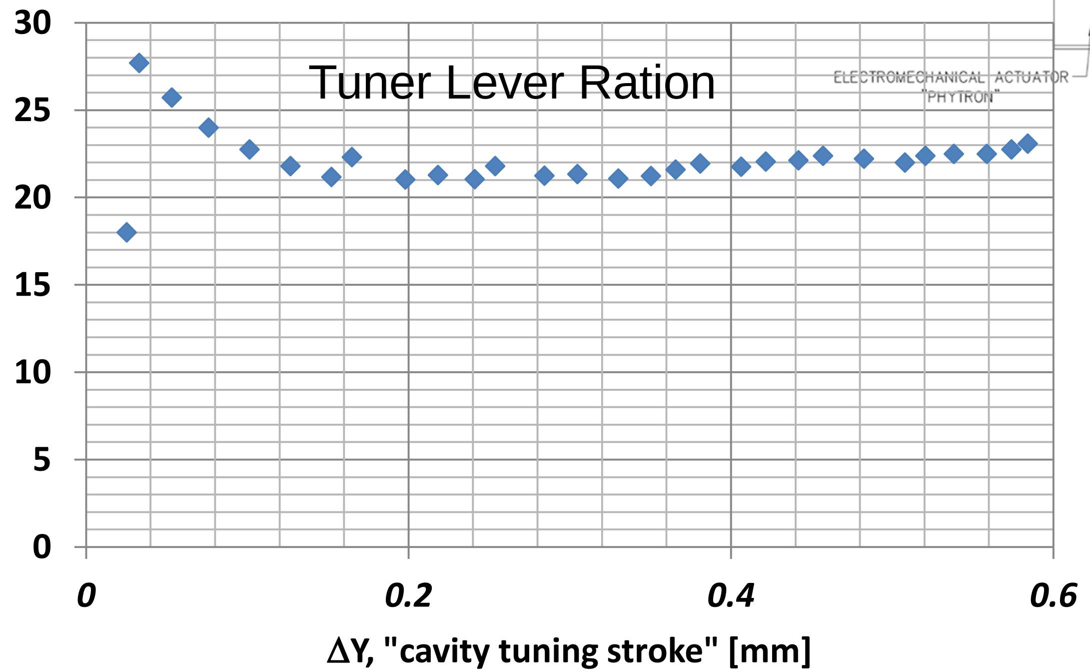
Test setup for measurements of the slow tuner performance.





Test of Slow Tuner (Lever ration measurements)





Plans for cold tests of Tuner at HTS

Preliminary:

- **End of September LCLs II He-Vessel will arrive at FNAL;**
- **Custom designed at PI piezo-capsules (4) will be delivered at FNAL ;** ***(2 piezo units with one 18mm piezo-stack built at FNAL---as an option B)***
- **At the end of October Tuner will be installed on He-vessel& cavity ;**
- **End of October tests of Tuner/cavity/He vessel system at HTS.**

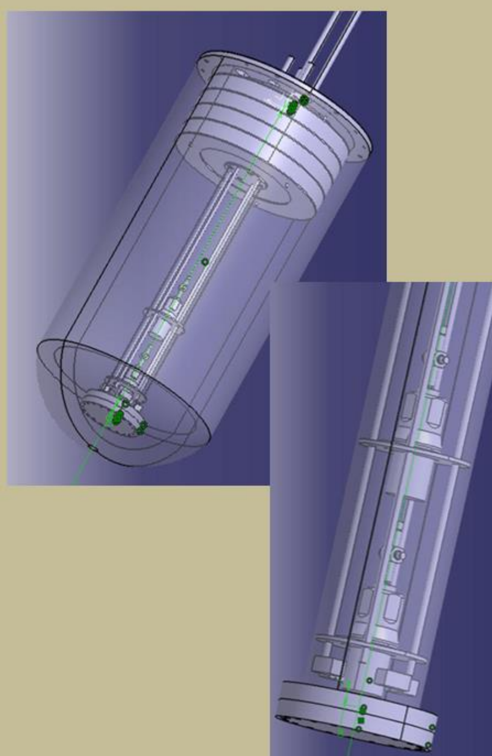
Electromechanical and piezo-actuator lifetime R&D Program

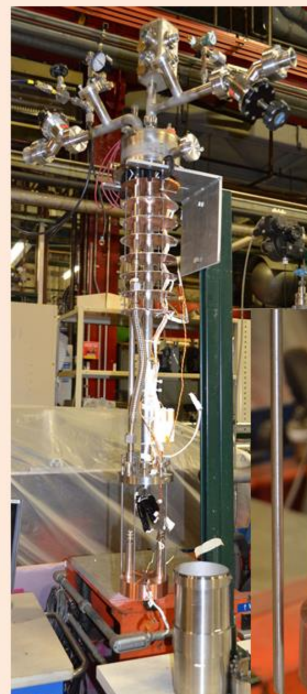
to study longevity of Tuner's components (electromechanical actuators and piezo)

*Two new **cold/insulated vacuum** test stands under construction at Technical Division: first to test electromechanical actuators (at LN2) and second to test Piezo (at LHe).*

Electromechanical actuator lifetime Test Stand.

Goals: study failure mode vs spindle rotations at different working loads



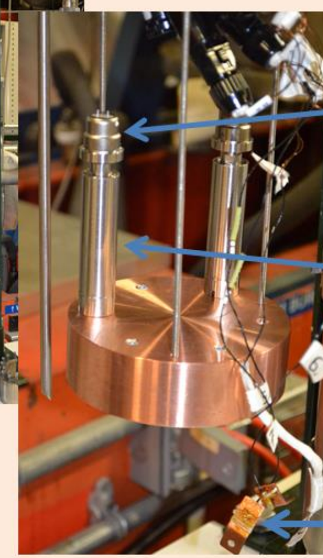


Inserts into LHe dewar with cryo/vacuum & electrical connections

Piezo Tuner Reliability Test Stand

Study Longevity vs:

- ***piezo driving voltage***
- ***shape of the pulses (slew-rate)***
- ***number of pulses***
- ***overheating of the piezo***
- ***radiation damage***
- ***etc …***



Geophone to monitor piezostroke

Capsule with Piezo inside

Cernox RTD to monitor Piezo temperature

Piezo Tuner Lifetime

In contrast with electromechanical devices, cold vacuum is an almost ideal environment for piezo actuators. Factors that can affect lifetime include:

- Environment, e.g. temperature, humidity, and voltage;
- Shear forces;
- Current Transients;
- Radiation Damage.

Piezo Tuner Reliability/ Radiation Damage

- The IPN/Orsay group has measured the degradation due to neutron radiation of piezo actuators from several manufacturers (http://cds.cern.ch/record/1087645/files/note-2007-004-SRF.pdf) . Included in their study were the PICMIA actuators manufactured by PI Ceramic that have been selected for the LCLS-IIsc tuner.
- The Orsay group concluded **"no major damage was observed but slight performance degradation may be due to aging effect, is measured**: these piezostacks are suited for use in cryogenic and neutrons radiation environment up

  to a total dose ~ 7.10^{14} n/cm^2" (5 x 10^4 Gy @ 1 MeV).
- Further studies using gamma sources available at FNAL are planned to establish damage limits on the LCLS-IIsc piezo actuators. Even with such studies, it will be difficult to make definitive statements about the effects of radiation on tuner lifetime until estimates of the tuner radiation environment become available.
- There are questions about **radiation damage of epoxy** (MasterBond EP21TCHT-1) , which used to glue ceramics end plate to piezoceramics (and we are planning to glue two 18mm piezo inside capsule).
- **Radiation damage to cable insulation** may also be a concern. Radiation damage thresholds for insulation published by NASA range between 10^3 Gy for Teflon and 5 x 10^7 Gy for Kapton (http://nepp.nasa.gov/npsl/wire/insulation_guide.htm)

Piezo Tuner Reliability/ Current Transients

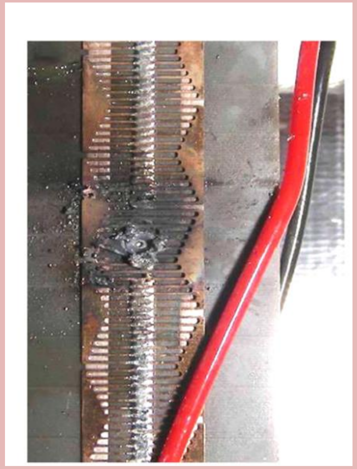
DESY reported that it maybe current transients which damage several piezos in FLASH

Recommendations from PI engineers: ***limit the current slew-rate***

“Piezo characterization and operation at FLASH” LLRF13, M.Grecki, DESY

Test in submerge LN2
Time duration – 76 days
Number of bipolar cycles - $3.3*10^9$
Excitation frequency - 500Hz
Average AC voltage 138 V

the destructive test has been performed (400Hz, rectangular waveform, ±70V). After ~2min rapid T rise has occurred.. Temperature went up to 120K – **actuator failed**



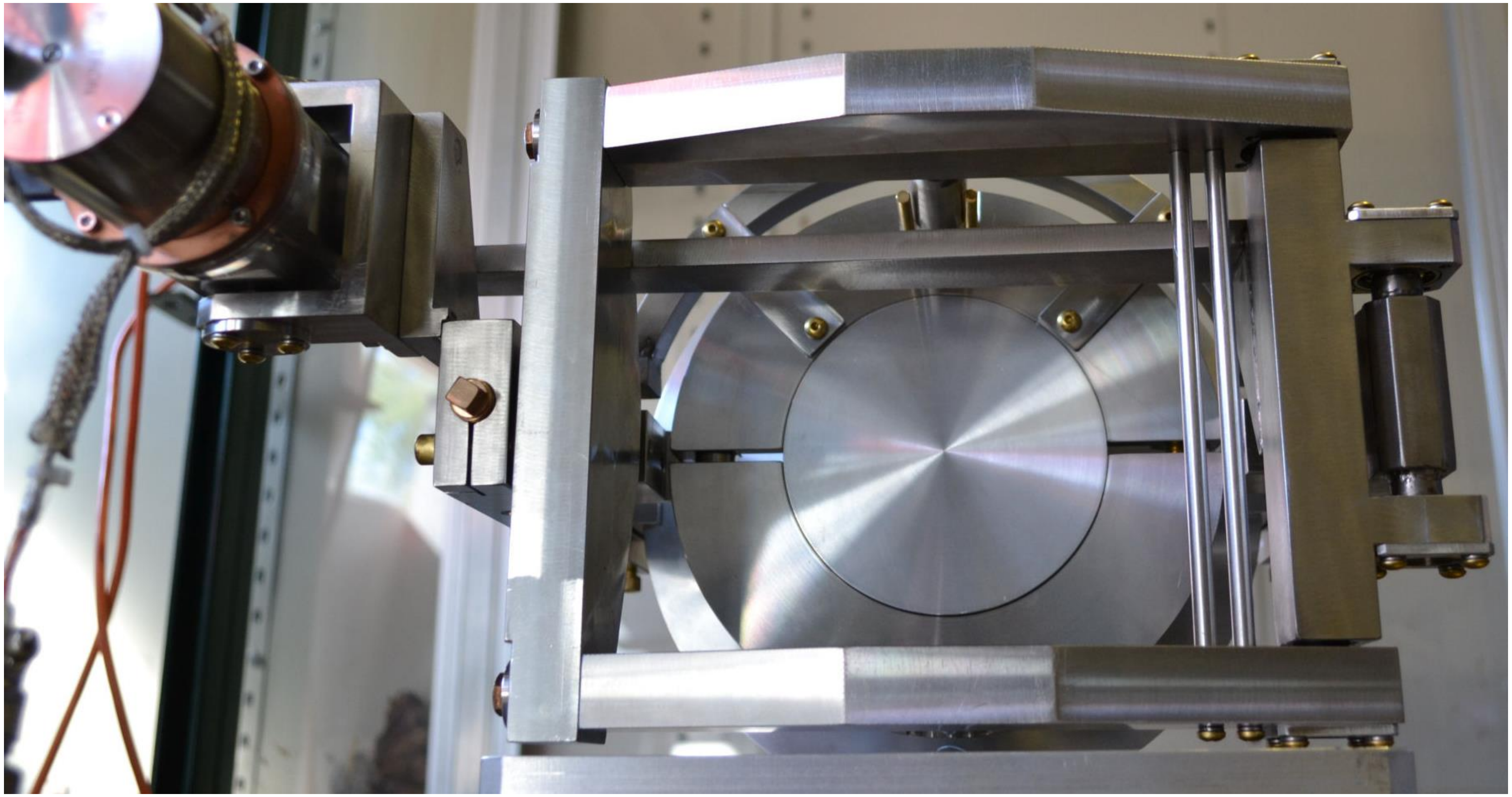
Conclusion from DESY/INFN study:
Piezo can be safely driven in bipolar mode, but the temperature must be constantly checked and kept low.
Electrical parameters of the piezo (capacitance) can be used to measure piezo temperature on-line, but other effects have to be taken into account.

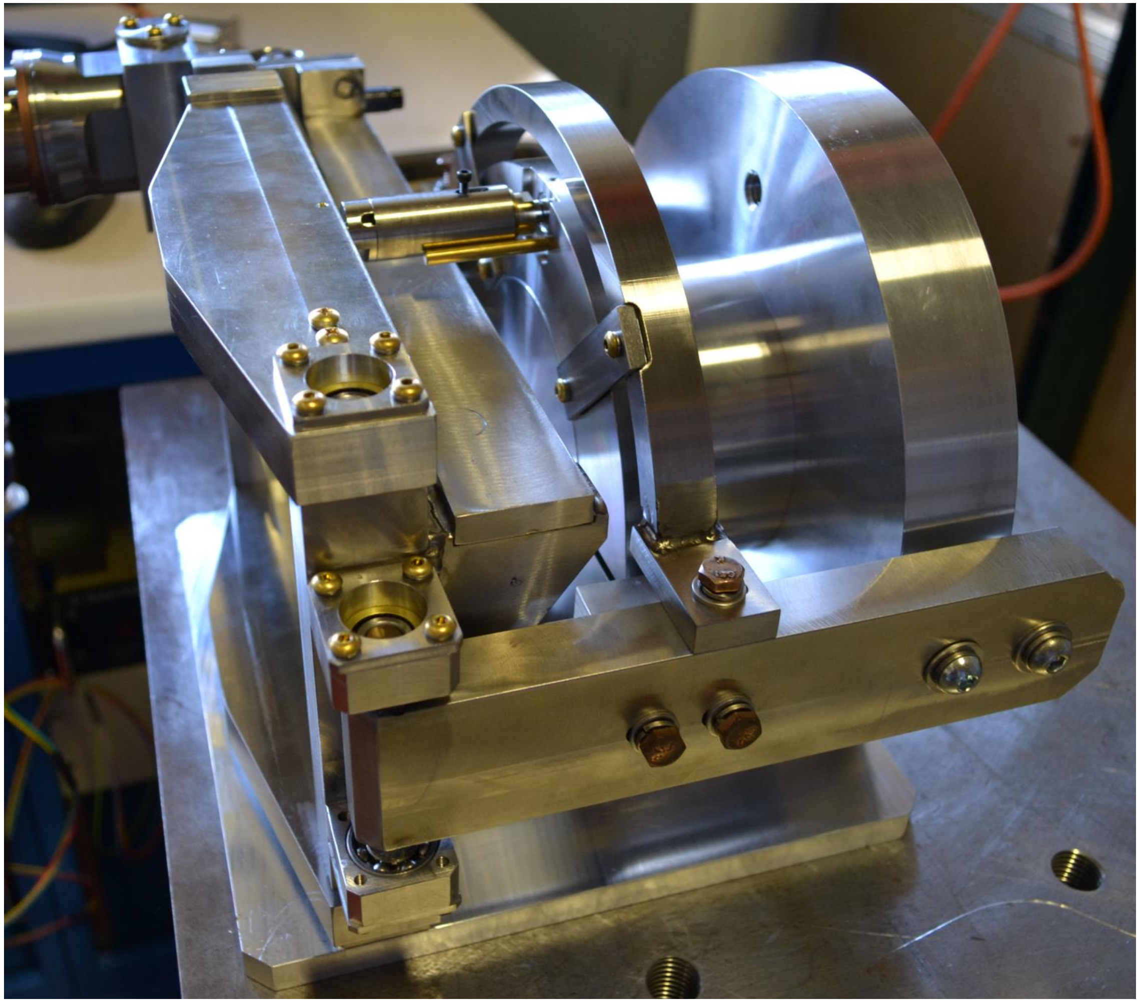
SUMMARY

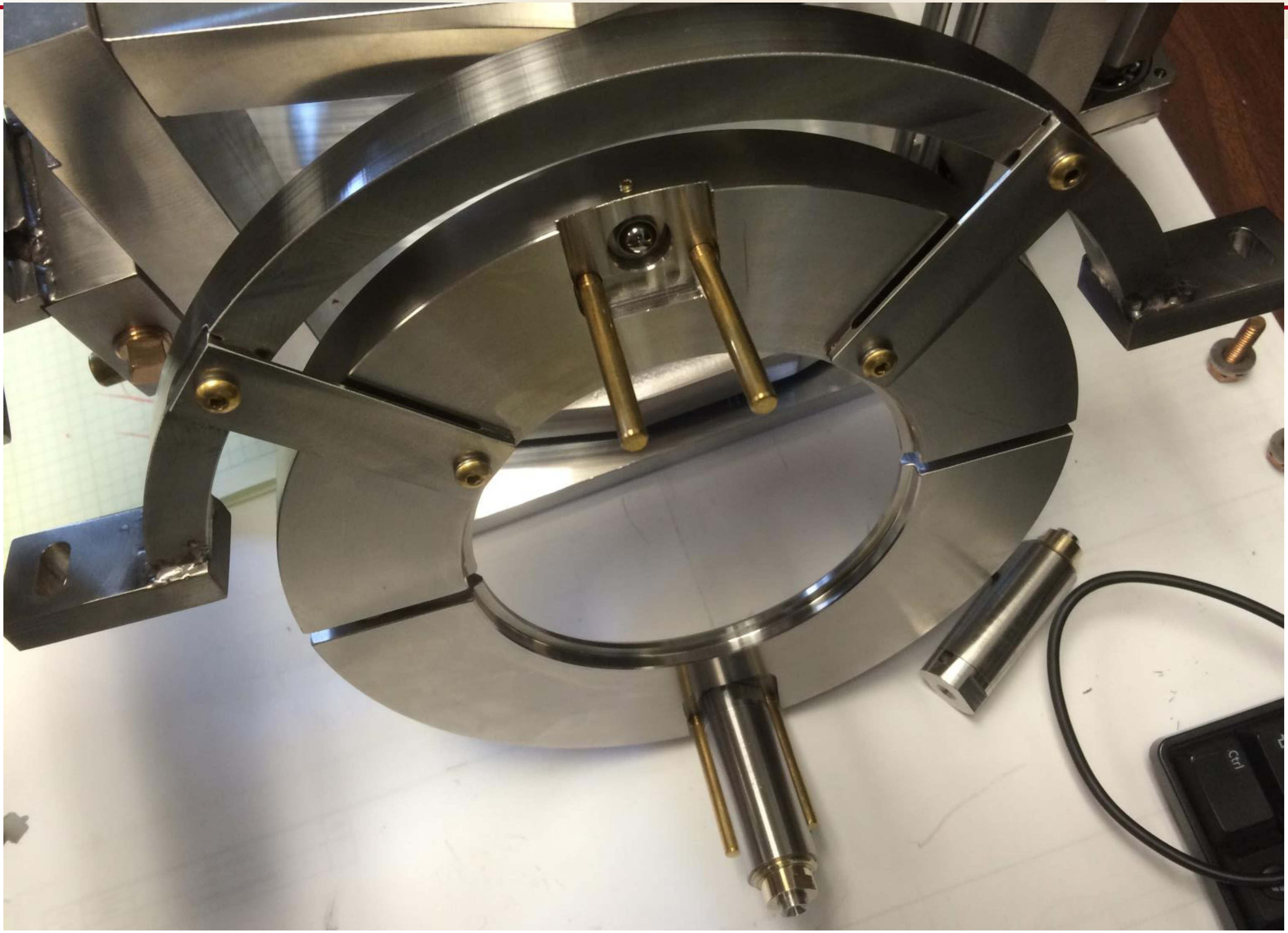
1. FNAL team designed LCLS-II Tuner, which adopted “double lever” features from SACLAY I Tuner. Major differences of LCLS II Tuner design related to Fast Tuner modifications and capability to replace active components through “special port”
2. Status of production of first (2) Tuner prototype :
   - Two tuner assemblies at FNAL. Assembled and went through preliminary tests
   - Phytron is working to deliver 3 units of Electromechanical actuators (mid-Sept.)
   - PI Ceramic is working to deliver 4 units of custom encapsulated piezo
   - Tuner will be test at HTS (cold) when He-vessel & cavity will be available. Preliminary HTS test will start at the end of October. Meanwhile warm tests of Tuner will take place.
3. Program for Tuner components reliability study is underway
   - Test stand for motor/actuators lifetime tests
   - Cold stand for piezo lifetime tests
   - Radiation hardness of piezo program

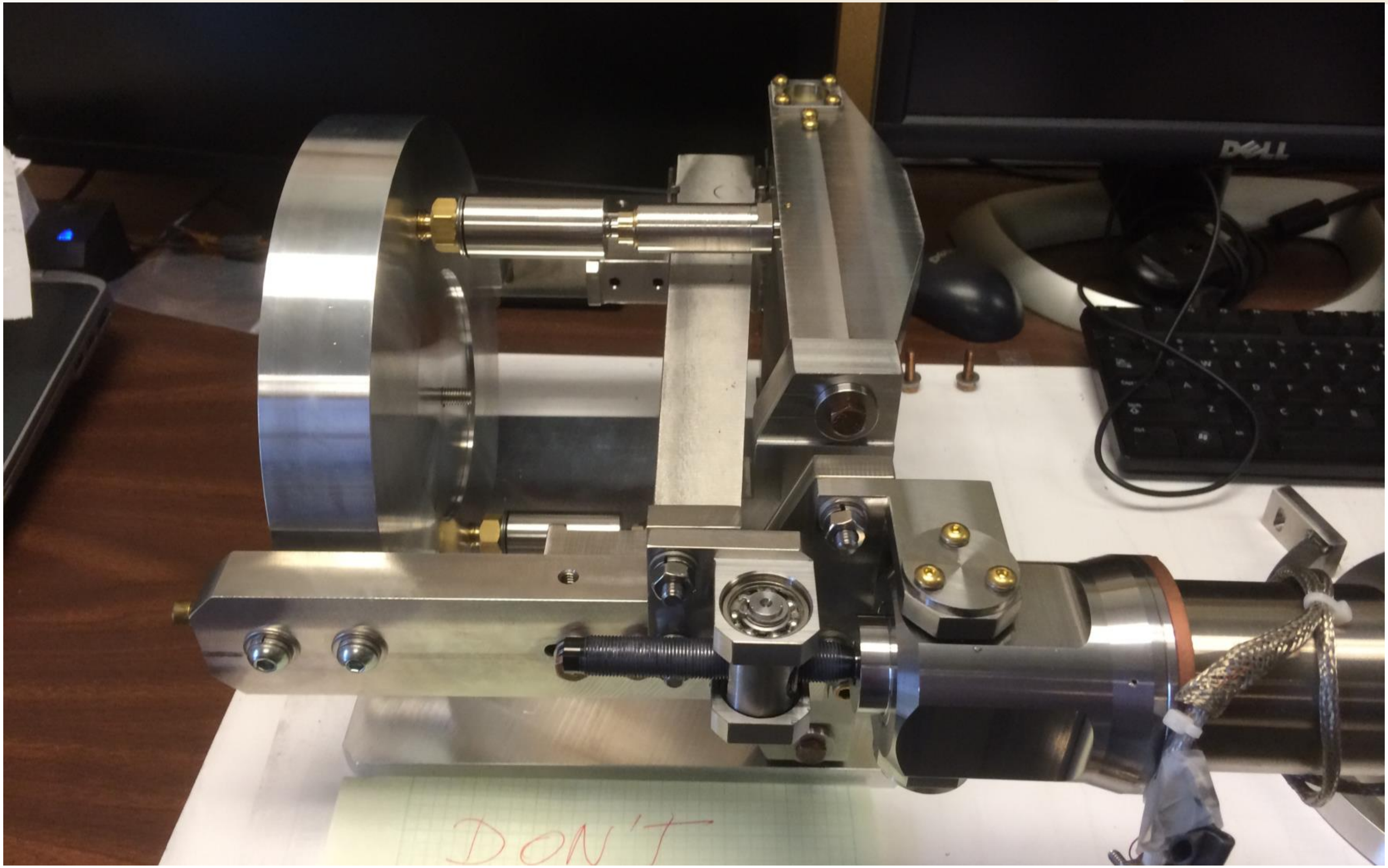
Additional Slides

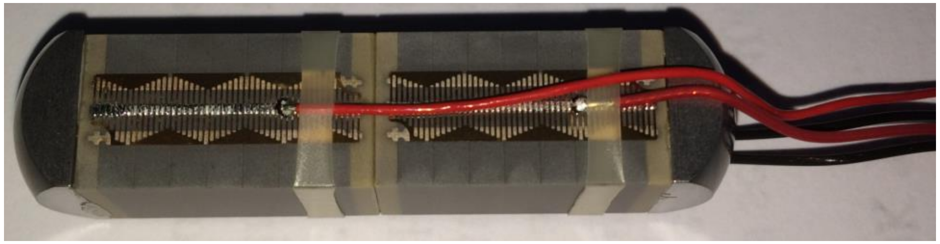
for discussion

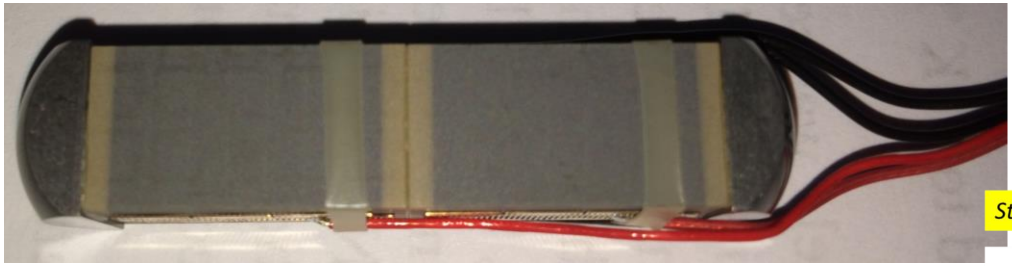




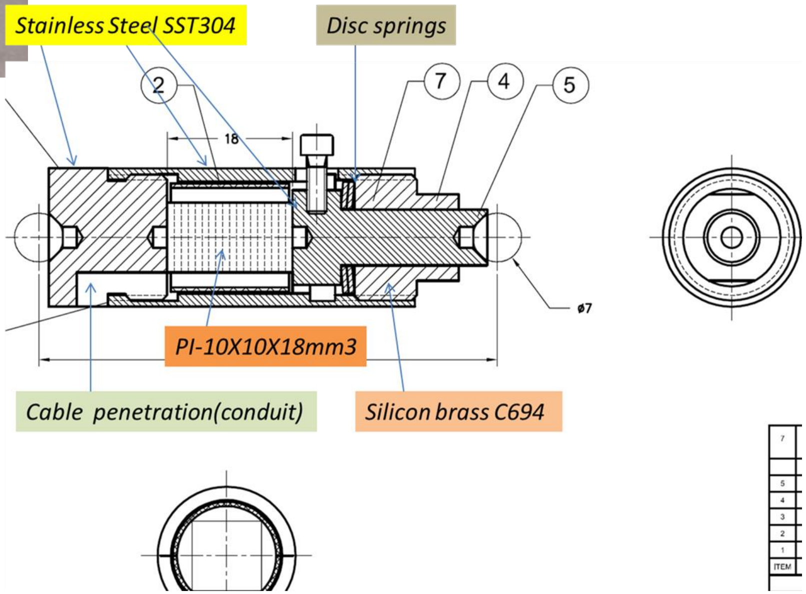

Ctrl


DELL
DON'T



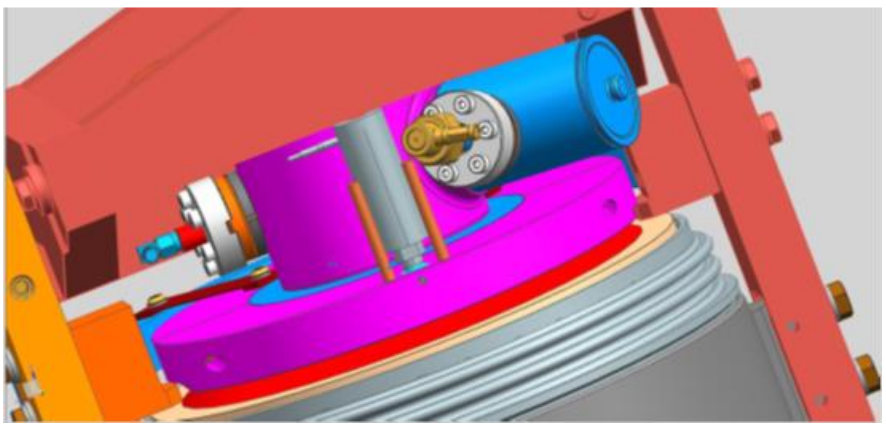


Option B


Stainless Steel SST304
Disc springs
2
7
4
5
18
ø7
PI-10X10X18mm3
Cable penetration(conduit)
Silicon brass C694

Issues.

- *Piezo-elements are closer to beam pipe → radiation level will be higher (?... How much? What is safe level for piezo?)*
- *There are adjustment screw to set (during assembly) uniform load on bottom and top piezo-capsule… Is this really Cons?*
- *Real estate occupied by tuner is expensive: integration issues*



HOM & Probe cables

Cavity alignment issues