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650MHz SRF Cavity TUNER

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PIP-II Fine Tuning Workshop, Saclay

26 June, 2018

Tuner Functional Specifications

- **Tuner must tune cavity (slow and fast) and protect cavity/He Vessel system during CM production cycle and operation of the accelerator**
- **The same design of the Tuner (with minimum modifications) must serve HB650MHz and LB650MHz cavities.**
- **Active tuner components (electromechanical actuator& piezo-stack) need to be replaceable through special ports;**
- **High reliability of tuner → longevity of the active components (electromechanical actuator and piezo-actuator);**
- **Tuner need to be build from materials with relative low magnetic permeability non-magnetic material (316L stainless steel or titanium) to preserve SRF cavity high Q0**
- **Tight requirements for slow/coarse & fast/fine tuning resolution → cavity has narrow bandwidth *(~29Hz)* and resonance control requirements** ΔF_{peak}*=20Hz (or* σ*=3.5Hz) in RF-pulse* and CW modes of operation*
- **High stiffness of the TUNER to minimize level of the LFD on the cavities**

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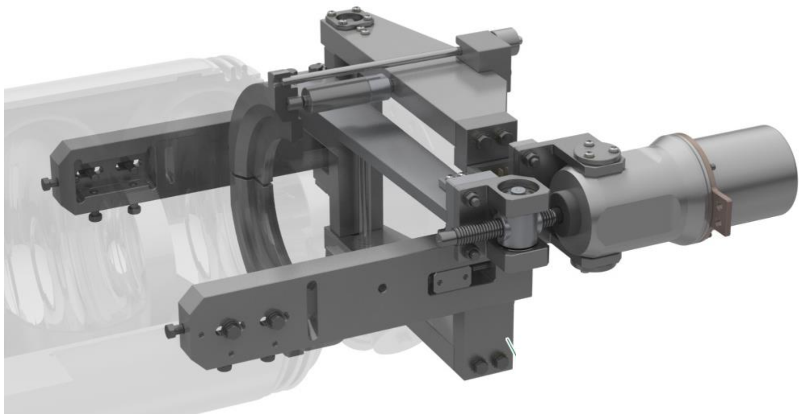
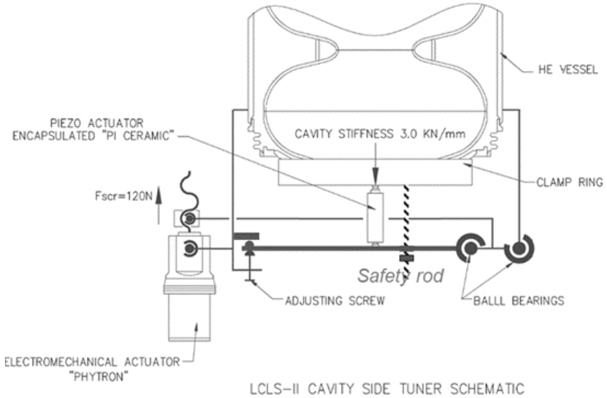
650MHz cavities parameters and specs for tuner

	beta	
	0.92	0.61
Cavity stiffness, (N/um)	3-4	3-4
cavity tuning sensitivity, [Hz/um]	160	240
bandwidth ($F_{1/2}$), [Hz]	29	29
Lorentz Force Detuning coefficient, $[Hz/MV/m]^2$	0.8-1.0	1.4-1.8
Cavity sensitivy to pressure, dF/dp [Hz/mbar]	20	20
Tuner sfiffness [N/um]	>40	>40
required coarse tuning range, [kHz]	200	200
coarse tuner resolution, [Hz/step]	1-2	1-2
fine tuner range, [Hz]	1200	1200
fine tuner range, [um] at T=20K (20% from RT)	*7.5*	*5*
fine tuner range, [um] at T=300K	*37.5*	*25*
cavity resonance control reqs (peak), [Hz]	20	20
fine(piezo) tuner resolution, [Hz]	1	1
max. forces on the tuner system, kN	*4*	*3.3*

*For 650MHz tuner design copy as much as possible from tuner design that FNAL team used for 1.3GHz elliptical cavity **LCLS II***
(including active components: electromechanical actuator & piezo-actuator)





- **Slow/coarse tuner – double lever (close to design of the SACLAY I);**
- **------------**
- **Solid connection to the He Vessel (no flexible joints);**
- **Push (cavity) compression tuning only;**
- **Safety rods (protect cavity);**
- **Piezo-actuator installed between tuner main lever and cavity flange;**
- **Compact tuner …fit to the short/short cavity;**
- **Piezo-actuator and stepper motor cartridge replaceable through special port;**

- **Reliable electromechanical actuator from Phytron**
- **Reliable piezo-actuator from PI**

Built ~ 300units
Assembled into CM ~80%
Cold tested ~60%

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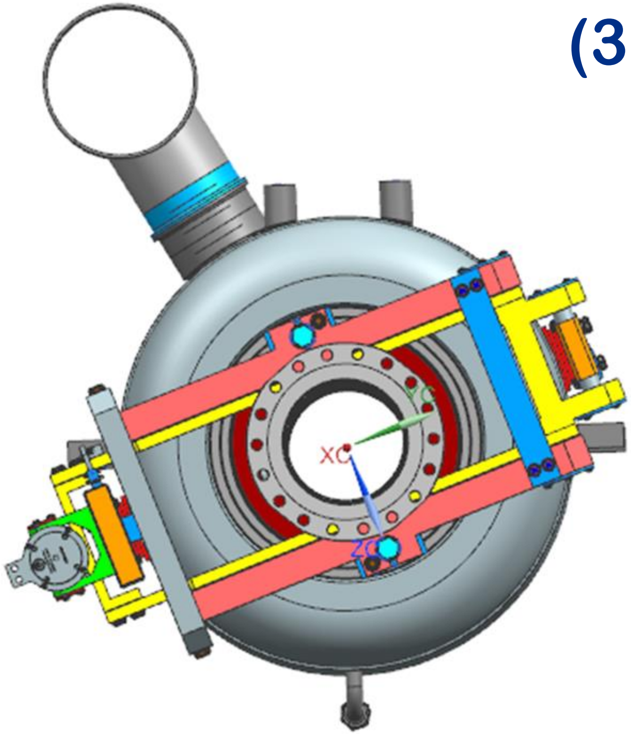
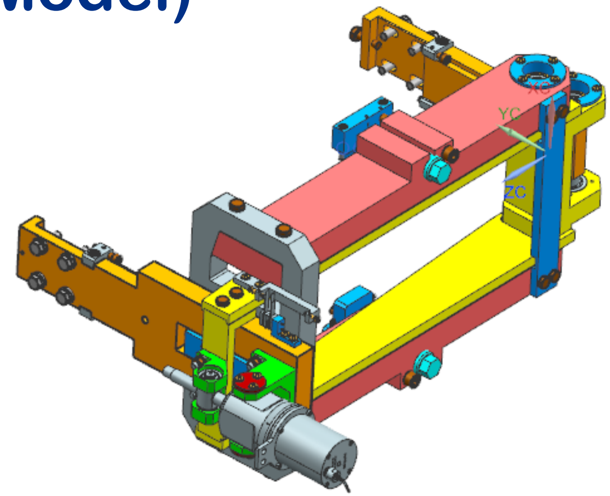
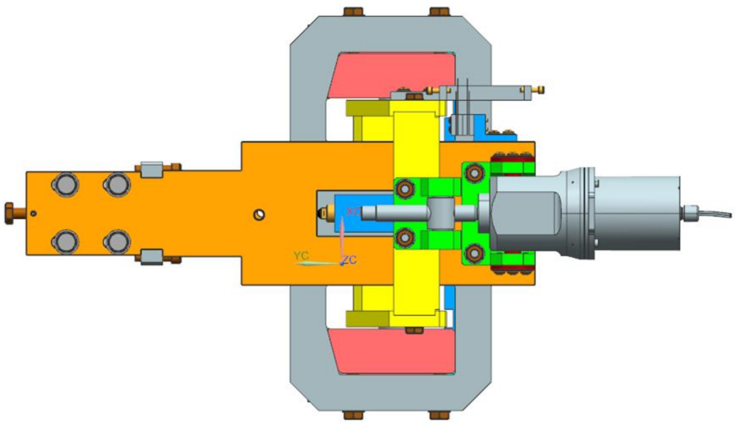
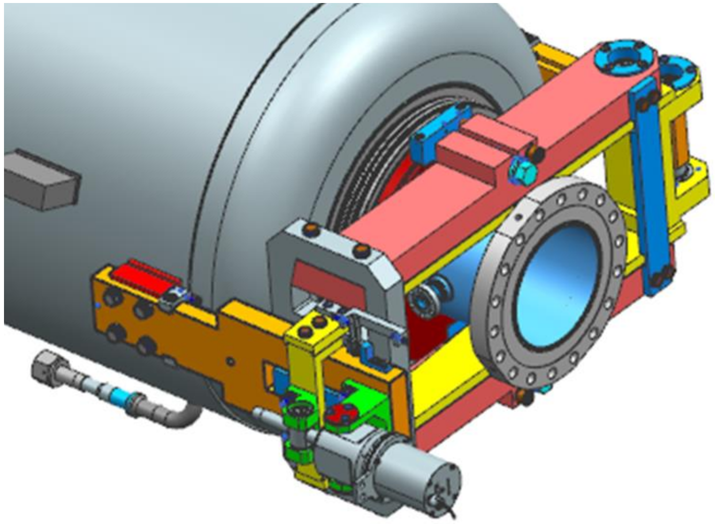
FNAL 650MHz Tuner (Version II) (3D Model)

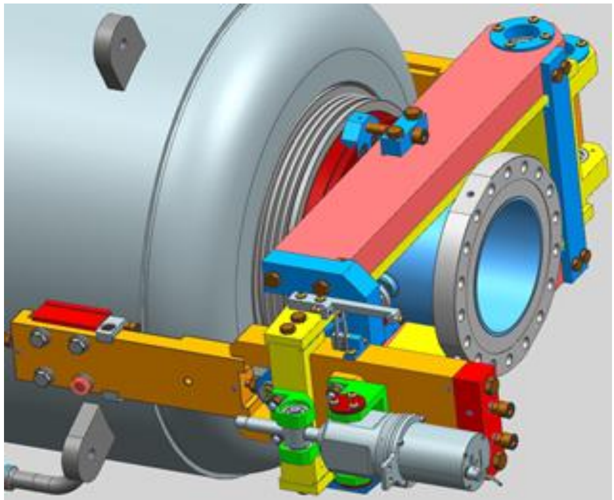






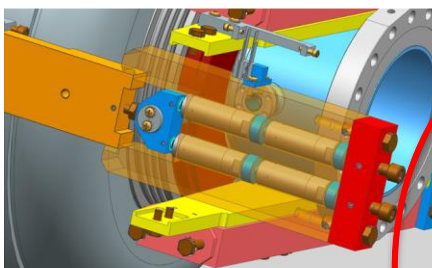


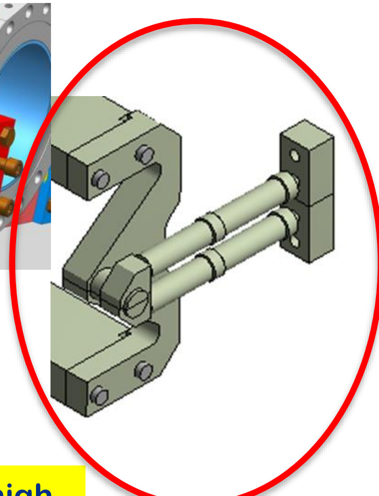
Major issues addressed during modification of the 650MHz Tuner Version I



- **Tuner stiffness**
- **Simplification of the design**

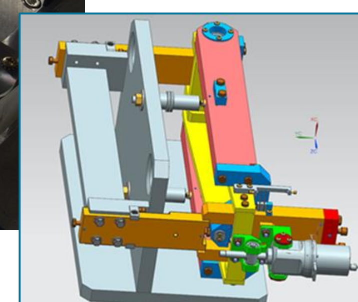
Initial ANSYS simulations (before prototype built) stated that ***K_{tuner}~65-70 kN/mm .***
Later we found that model/simulation was not correct… but only after we built first prototype.
Measured stiffness on the prototype was ~30kN/mm





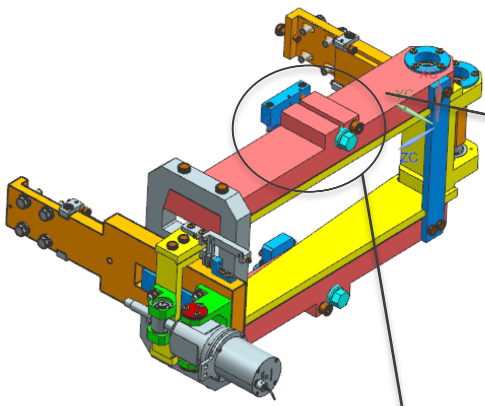
Version I. Cartridge with 4 piezos located on the same side as motor

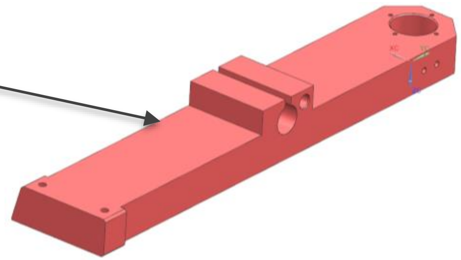
(to satisfy cavities with high stiffness K_{cavity}=20kN/mm)

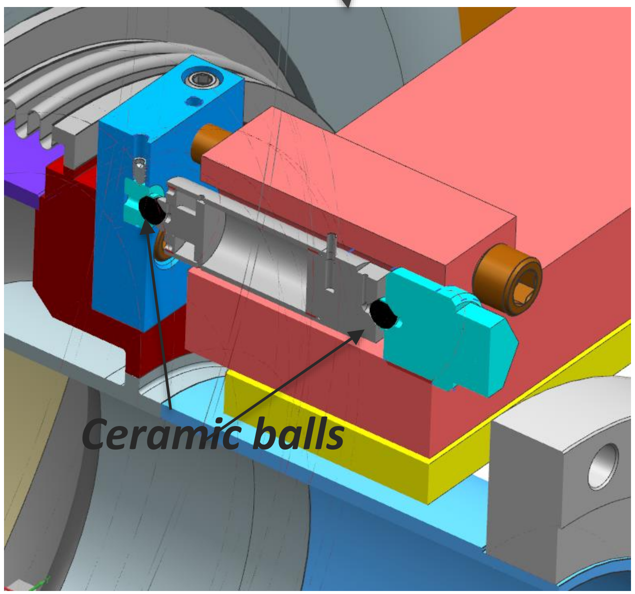


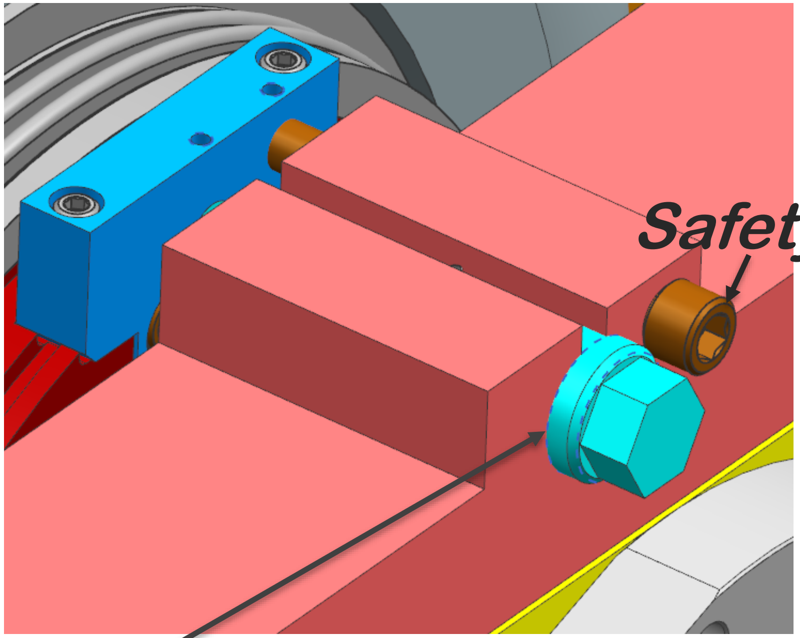
650MHz Tuner (Version I) assembled on the test stand)

Details of the 650MHz Tuner (V2) Fast/Fine Tuner design





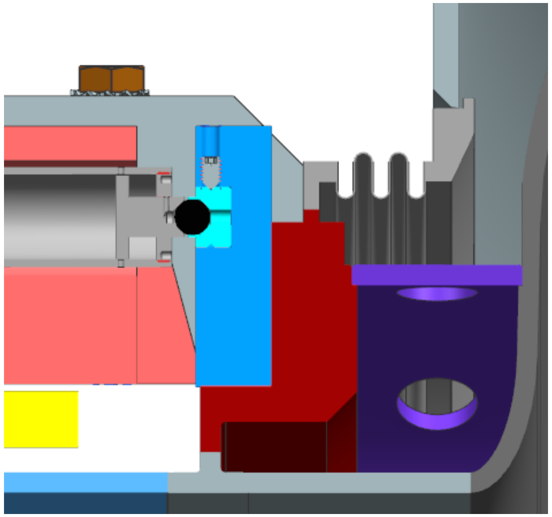


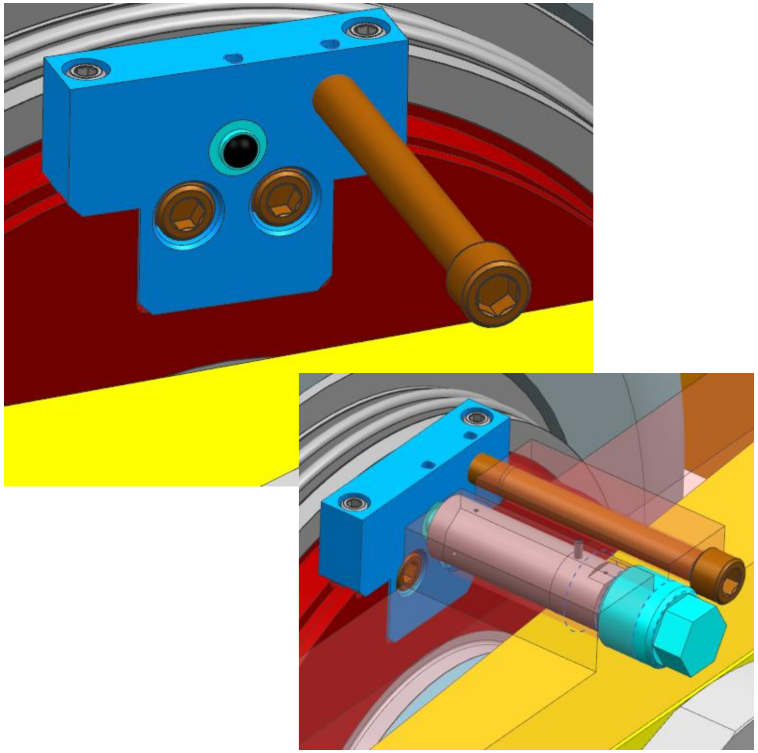


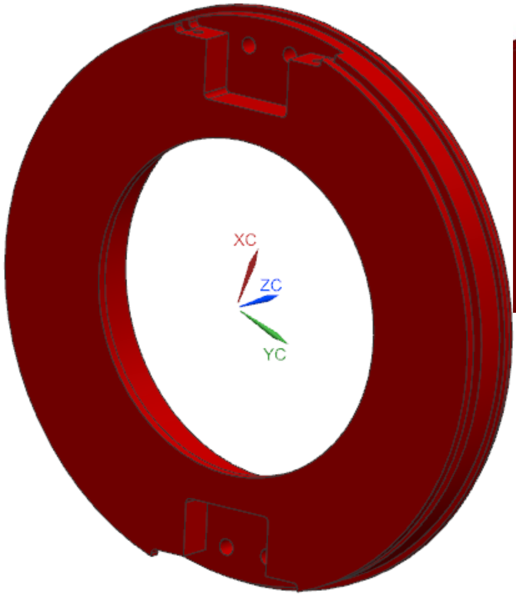
Details of the Tuner-to-cavity Interface

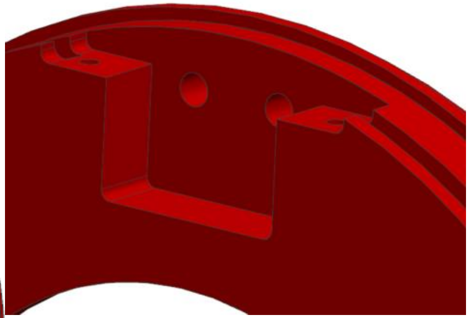
No “split-ring” parts that mounted on the alignment ring …unlike 1.3GHz cavity interface

Interface ring (Nb-Ti) welded to beampipe & cavity 1st cell



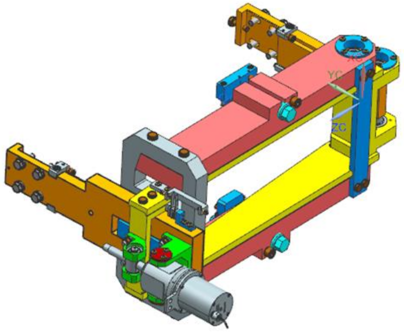


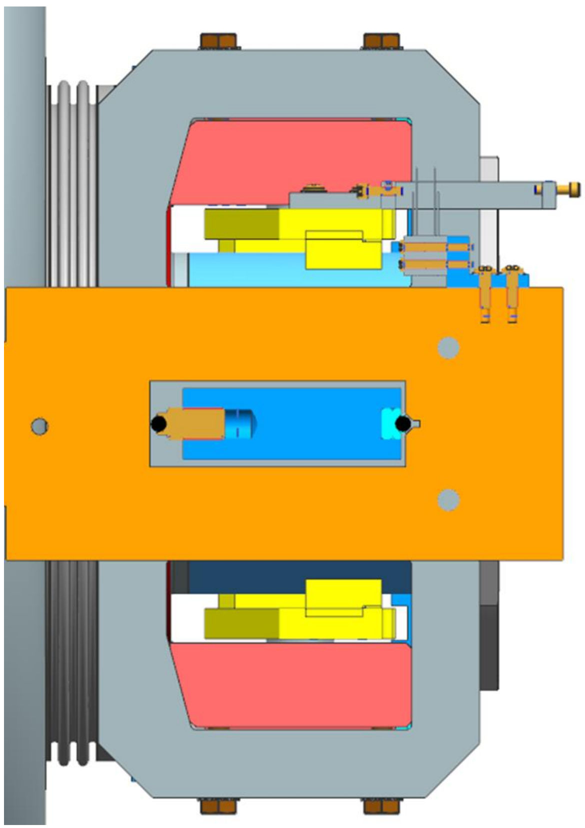


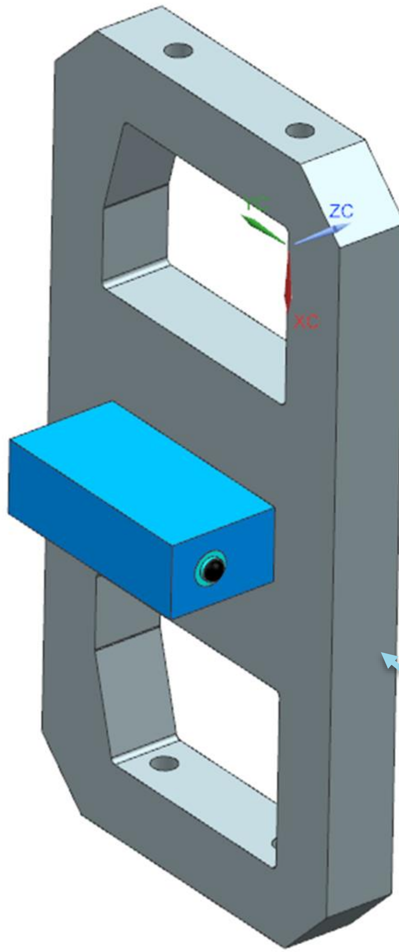


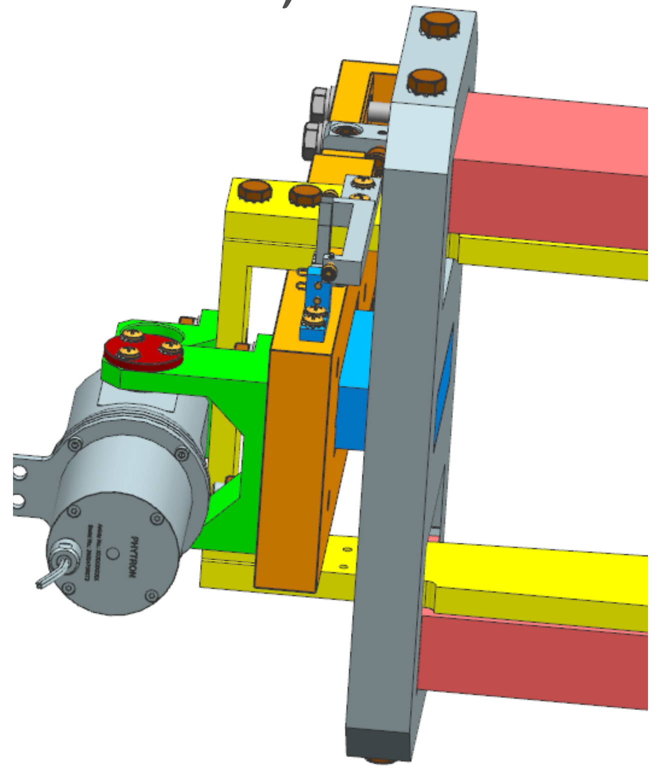
Nb-Ti ring (serve as interface to the tuner)

Details of the Tuner design
(from the motor side)









Part that lock together top & bottom main levers & transfer forces from the cavity on the right tuner arms

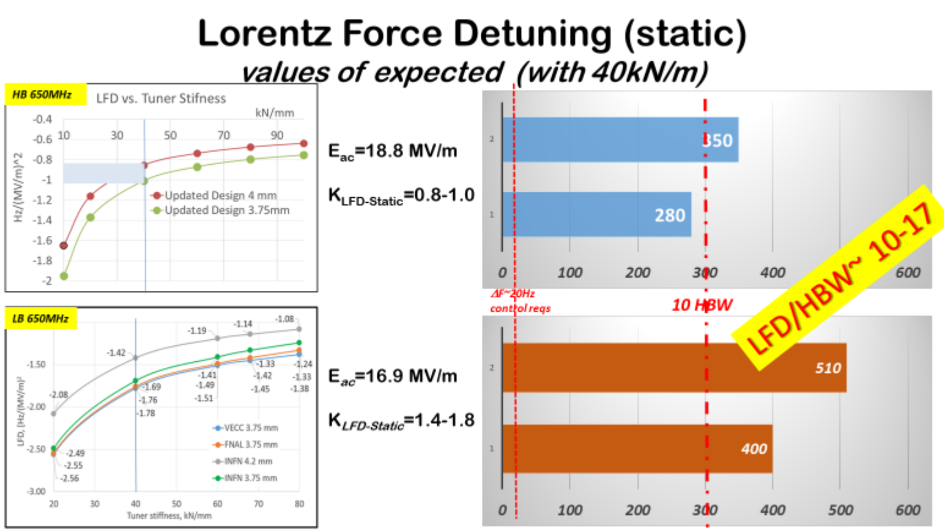
ANSYS Simulation of the stiffness for Tuner-Dressed Cavity system

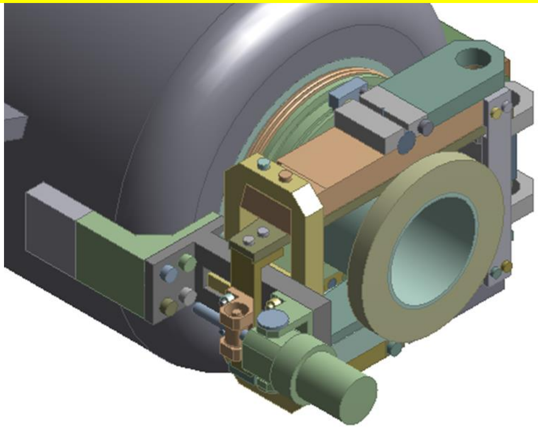
Stiffness of the Tuner frame <u>K_{tuner_frame} ~140kN/mm</u>
(without "piezo" & transition ring)

Stiffness of the overall system <u>K~42kN/mm</u>

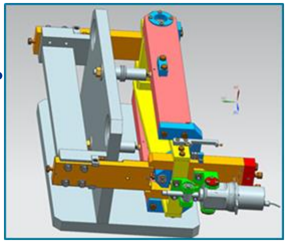
<u>At this stage we are consider this design as optimal from the point of view tuner stiffness. Increasing stiffness MORE will require significant modification of the cavity-tuner interface & new (large cross-section) piezo-actuator development</u>

ANSYS simulations
K_{frame}~600kN/mm
But $K_{tuner/dressed\ cavity\ system}$~55kN/mm

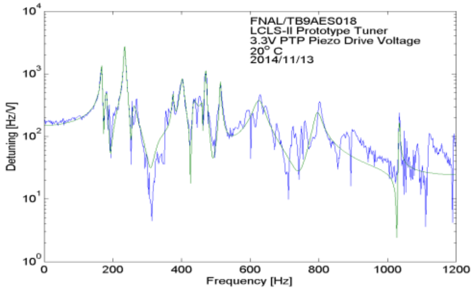




- **Tuner manufactured. Will be arrive from vendor in 1 week.**
- **Small design modification of the test stand (cavity mock-up) finished.**
- **Parts in FNAL machine shop. Will be ready next week.**
- **Assembly of the tuner on the stand**
- **Testing main tuner parameter (July, 2018)**
  - ***slow tuner characteristics (calipers)***
  - ***piezo-tuner characteristics (laser displacement system)***
  - ***tuner stiffness evaluation (load cells)***



- **Testing tuner on the first dressed 650MHz cavity (warm) (as soon as cavity available)**
  - ***transfer function measurements***
  - ***etc…***



#	f(Hz)	tau(ms)	kappa(Hz/V)	Strength
1	**235**	49	14.5	***0.65***
2	**168.1**	41	6.86	***0.1***
3	**471.2**	46	5.79	***0.09***
4	**402.2**	17	1.29	***0.04***
5	**232.6**	126.4	1.29	***0.03***

LCLS II Tuner
On the dressed warm cavity

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Tuner Reliability & Maintainability (1)

(Lessons learned from previous projects (SNS) & LCLS II experience to PIP II project)

Maintainability →

Tuner access port + design of the tuner allowed to release/replace active components without tuner dis-assembly.

Lessons learned: SNS …24 tuner failures (for 80cavities)… large size high power coupler port allowed to reach/maintain tuner

LCLS II CM vacuum vessel have tuner access ports
We don't have any tuner failure so far after cold testing of 60% of tuner s installed on inside CMs…. but tuner access ports used by team for many other sub-system fix/maintenance issues: HOM, etc.

LCLS II Tuner
Visible through access port

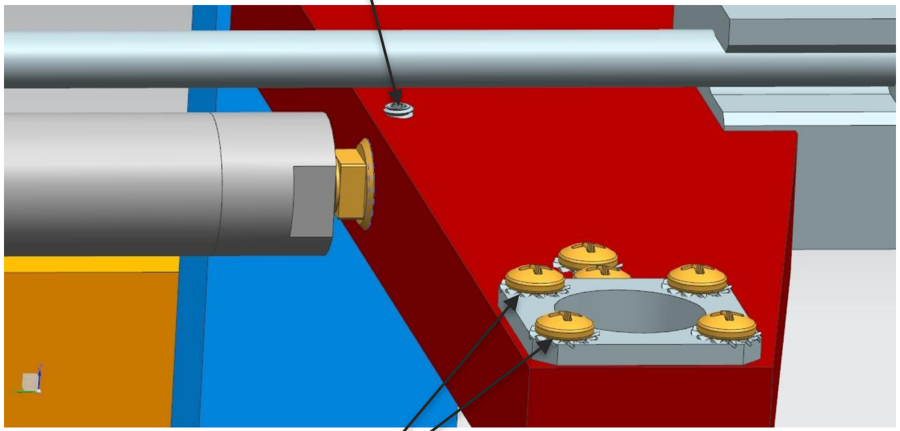
Tuner Reliability & Maintainability (2)

(Lessons learned from previous projects (SNS) & LCLS II experience to PIP II project)

Reliability→

Tuner mechanical frame long-run reliability : LCSL II approach → <u>all screws have lock-washers + set screw+ lock-tight glues</u>

Vibration of the tuner during transportation and during the 20-30 years of operation.



Tuner Reliability & Maintainability

(Lessons learned from previous projects (SNS) & LCLS II experience to PIP II project)

Reliability→

Active Components:

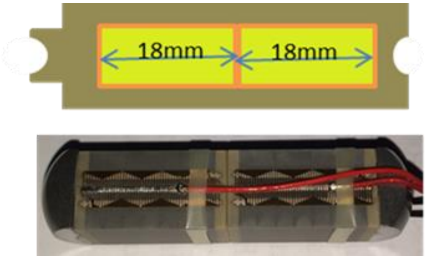
<u>1. Electromechanical Actuator</u>

Phytron electro-mechanical actuator (stepper motor; gear-box; shaft-traveling nut).

Phytron actuator

<u>2. Piezo Actuators</u>

PI capsulated preloaded piezo-actuator.

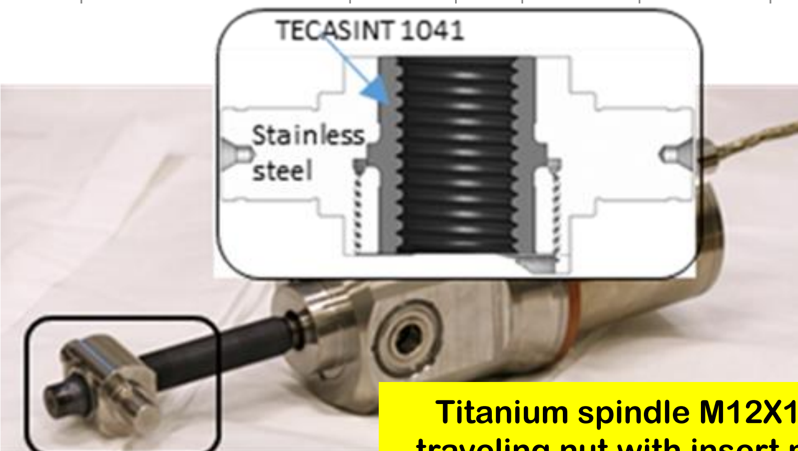


PI piezo for LCLS II

650MHz tuner will use active components that were developed for Project X and LCLS II Projects.

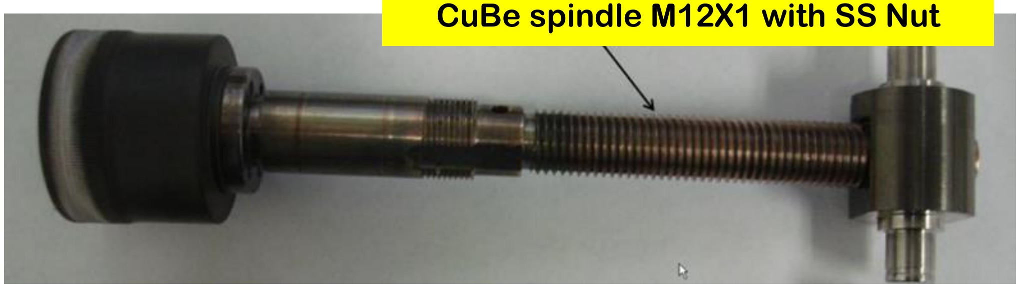
Phytron electromechanical actuator

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



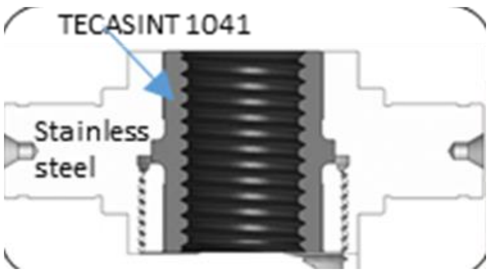
+/-1300N

Titanium spindle M12X1 with SS traveling nut with insert made from rad. hard material TECASINT 1041 (polyimide; fillers 30% Molybdenum disulfide (MoS_2)
VS
CuBe spindle M12X1 with SS Nut



Planetary gear
vs
Harmonics drive

Phytron Actuator Accelerated Lifetime and Radiation Hardness tests

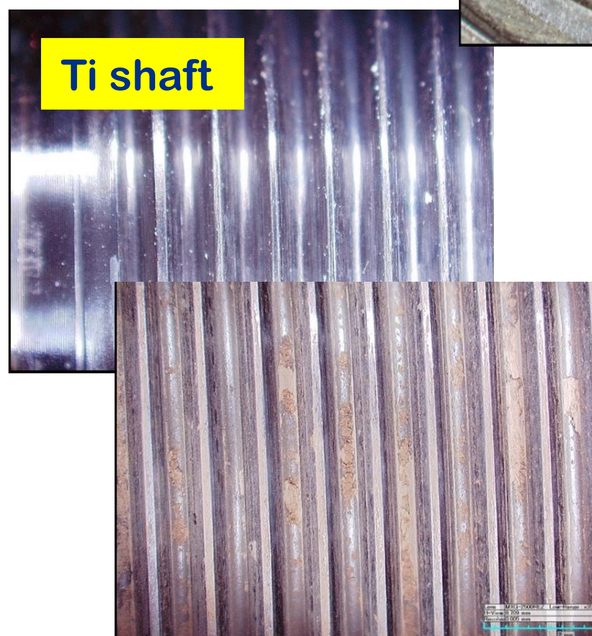


After irradiation to the dose 5*10^8Rad there was no any degradation in the electromechanical actuator components:

- ***Windings of the stepper motor***
- ***Limit switches***
- ***Traveling nut***

Long run at cryogenics/insulated vacuum environment

Ti shaft



Ti shaft has no any degradations

Successful run for 10 lifetime of the regular operation.

TECASINT Insert

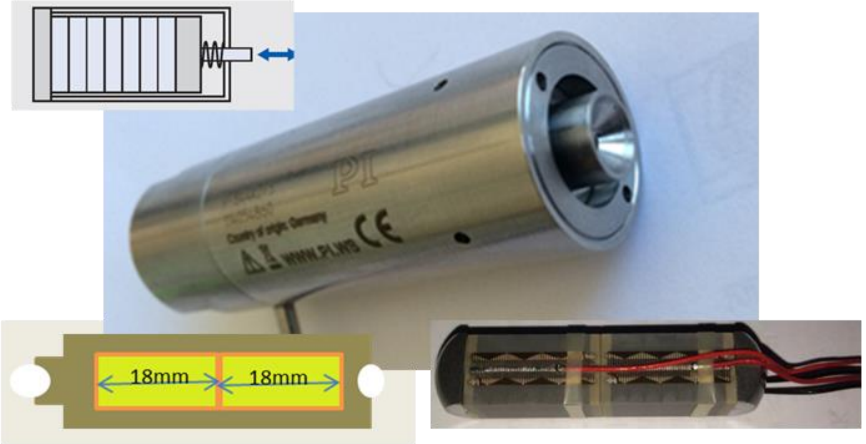
before

after

there are signs of wear on the nut, but there is no significant damage seen on the threads

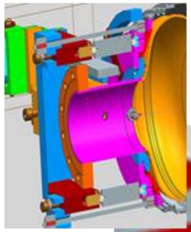
Material found between spindle thread (Molybdenum disulfide (MoS_2))

LCLS II piezo-stack (designed and built in collaboration with PI)

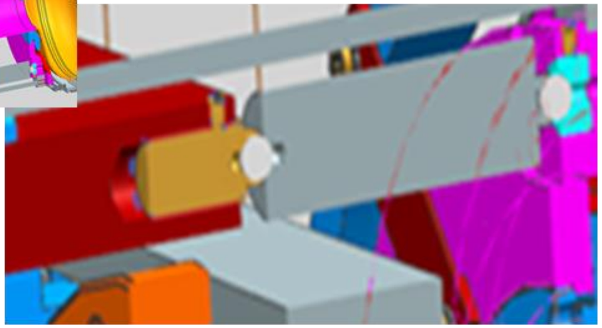


LCLS II configuration allowed for max. length 36mm piezo
Piezo capsule build with piezo stack made from 2*18mm piezo
LCLS II fast tuner can deliver 3kHz (V=120V) (all 4 piezo)

- ***Internal preload (800N at 2K)***
- ***Minimization of the shearing forces***
- ***through balls connections***
- ***Piezo-ceramic stack glued to substrates (as recommended by all piezo companies)***
- ***PI using patented technology … taking into account different thermo-expansion coefficient for piezo-ceramics and stainless steel***
- ***316L stainless steel construction (High Q0 reqs)***
- ***Wiring with kapton insulation wires***



Ceramics balls



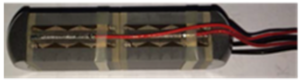
Fixture with piezo-capsule was cool-down inside LN2, installed into INSTRON and measured S vs Forces

Piezo Survived 25kN test
2Piezo-stacks ==50kN
(10kN requirements)

High reliability of tuner components (piezo-actuator)
Accelerated Piezo Lifetime test at FNAL

Y. Pischalnikov, et al
"RELIABILITY OF THE LCLS II SRF CAVITY TUNER", SRF2015

Designated facility at FNAL to test piezo at the CM environment (insulated vacuum and LHe)



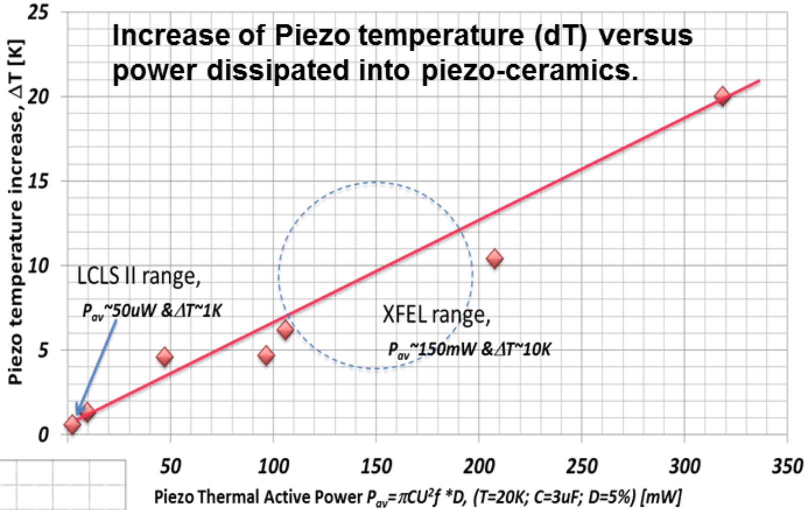
Insert into LHe dewar with cryo/vacuum and electrical connections

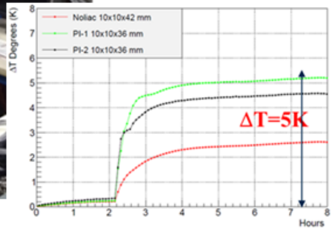
Capsules (up to 5) with Piezo-stacks Mounted on the copper block

- RTD (Cernox) –to mount on Piezos
- Geophones (to monitor piezo stroke)

Accelerated piezo-stack lifetime test
$2*10^{10}$ *pulses* $(V_{pp} = 2V \; \& \; F = 40Hz)$
20years → 2 month (40Hz→5kHz)

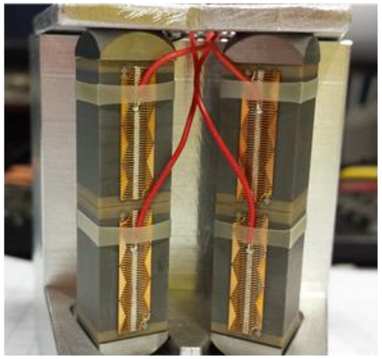
LCLS II --- ***P_{av}~ 50µW (40Hz, 2V)***
During ALT at 5kHz ***P_{av}~ 6mW (ΔT~2K)***

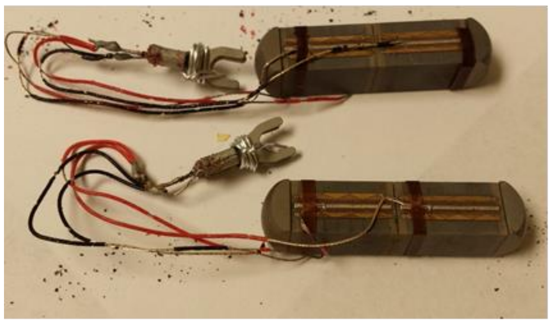




LCLS II Tuner piezo-stacks run for <u>$2.5*10^{10}$ pulses (or 125% of LCLS II expected lifetime</u>) without any degradation or overheating

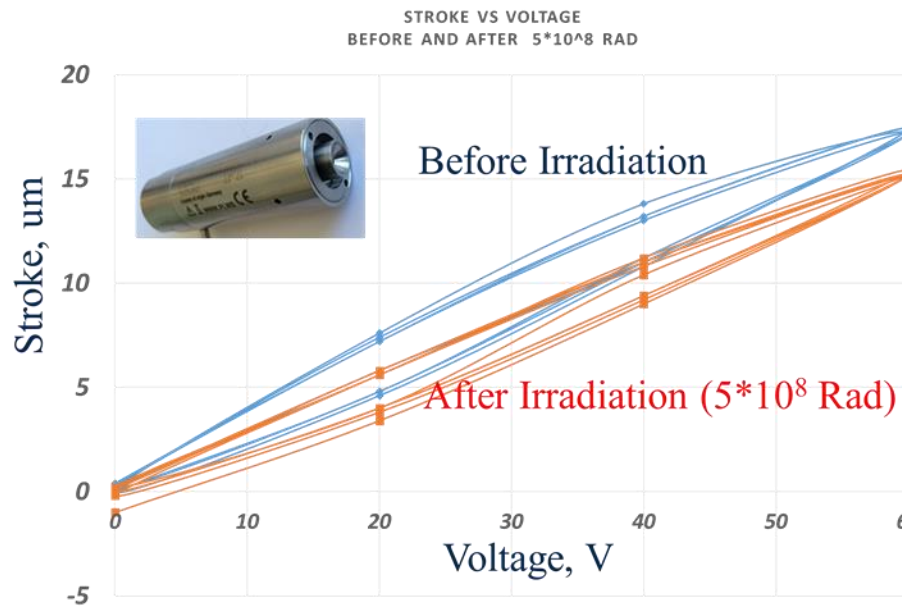
Irradiation of the Piezo-stacks up to 10^9Rad (gamma)





Sample A($5*10^8$ Rad) Sample C (0 Rad)

Discoloration of the thing layer of Epoxy



Stroke of the piezo-stack decreased only on 10% after irradiation up to 10^9 Rad

Summary

- **650MHz cavity tuner developed at FNAL based on proven LCLS II tuner design.**
  Version 2 tuner optimized to simplify design and increase tuner stiffness

- **Tuner reliability and maintainability addressed the same way as it was done for LCLS II project:**
  - designated ports
  - locking all fasteners
  - reliable active components (Phytron- electromechanical and PI piezo actuators)

- **Tuner (V2) prototype built and will be tested (on cavity mock-up) in a month.**

- **FNAL's Resonance Control is working on the all aspects of the SRF (650MHz) cavities frequency controls:**
  - Developments and testing tuners
  - Passive resonance control aspects of CM design
  - Active resonance control (development of algorithms for RF-pulse and CW modes of operations)
  - Development (in collaboration with PI) new type of piezo-actuators for high dynamic rate operation.

LFD $_{static}$ .vs. Tuner Stiffness