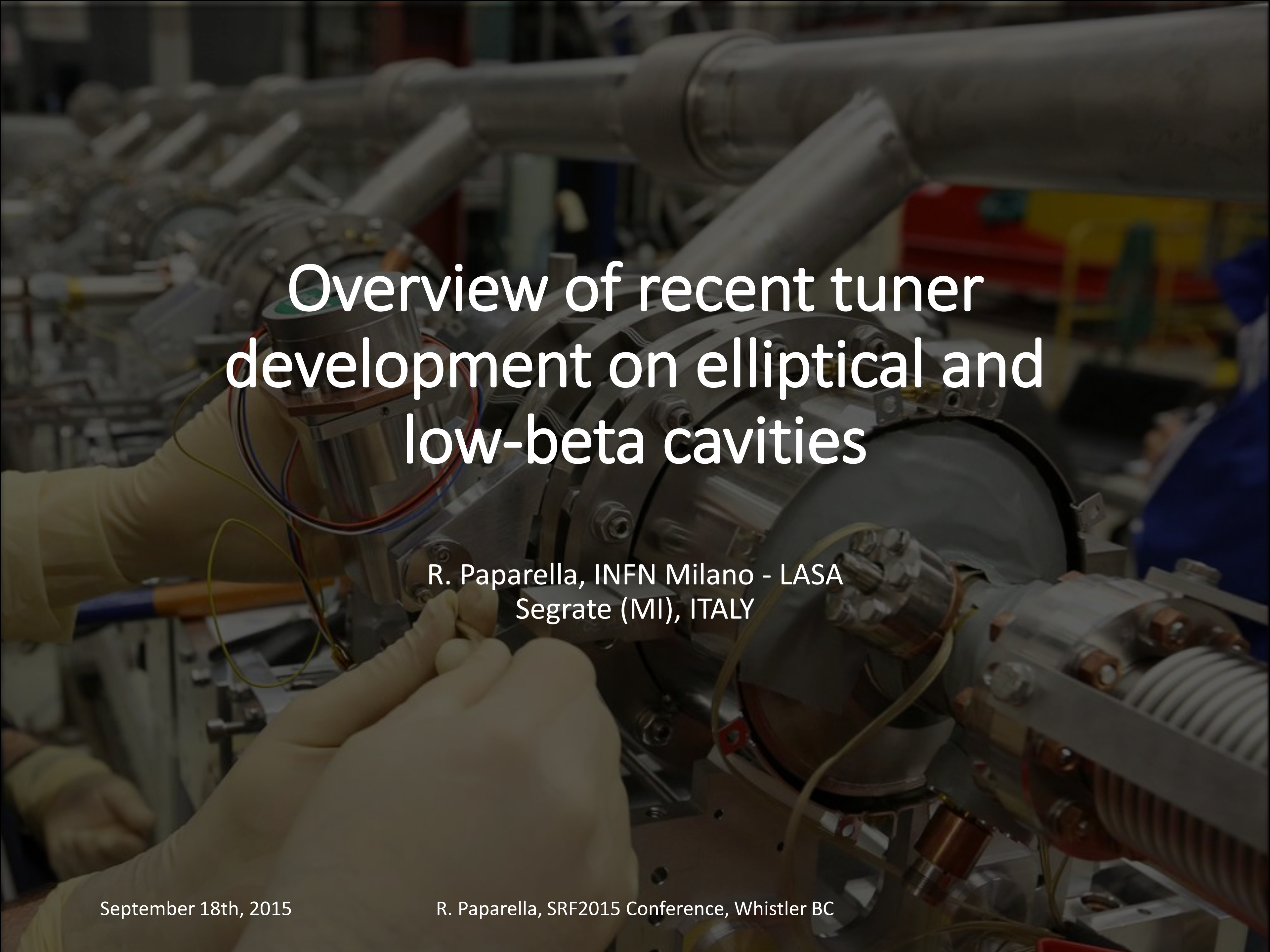


Overview of recent tuner development on elliptical and low-beta cavities

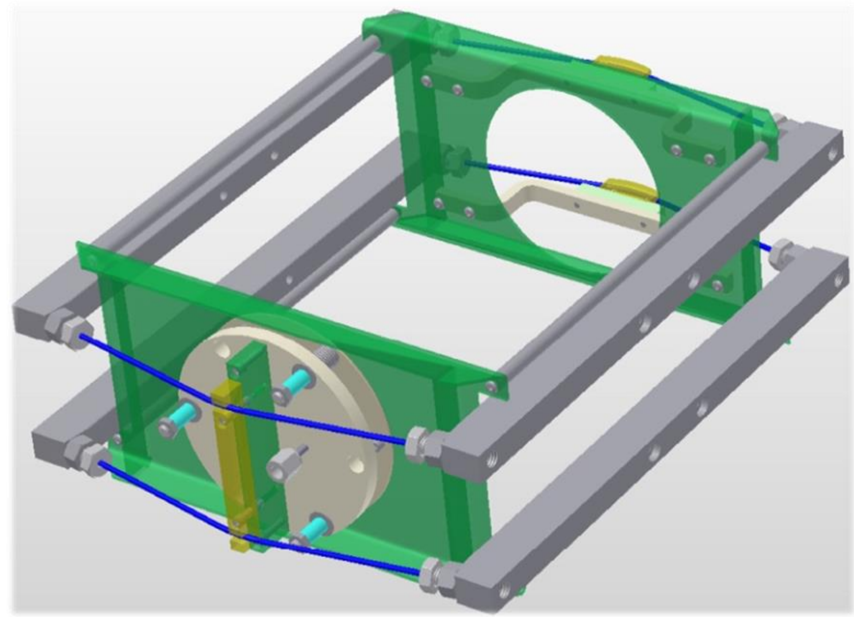
R. Paparella, INFN Milano - LASA
Segrate (MI), ITALY

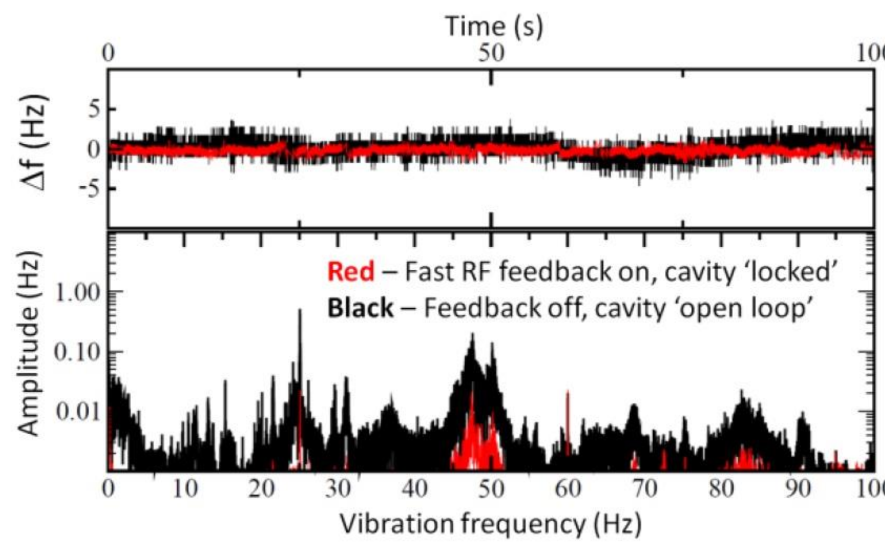
Layout of the talk

- Examples and recent tuner-related results
  - QW and HW resonators
    - ATLAS
    - Spiral 2
    - FRIB
  - Spokes
    - ESS
  - Elliptical
    - ARIEL
    - European XFEL
    - LCLS-II
    - ESS, SPL
  - Other ongoing tuner activities

ATLAS at ANL

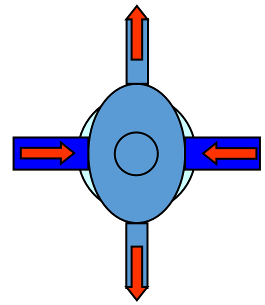
- Efficiency and Intensity Upgrade, CM with 7 72 MHz, β=0.077 QWR, 4 K
- Separated slow and fast tuning action, pneumatic tuner with he gas actuating bellow.
- Fully passive MP damping currently implemented:
  - Reduced cavity pressure sensitivity by design
  - Mechanical damper
  - Centering of central conductor up to 0,1 mm accuracy
- MP level confirmed in operation at +/- 2 Hz pp (closed loop), only 5% of the foreseen fast tuning range!

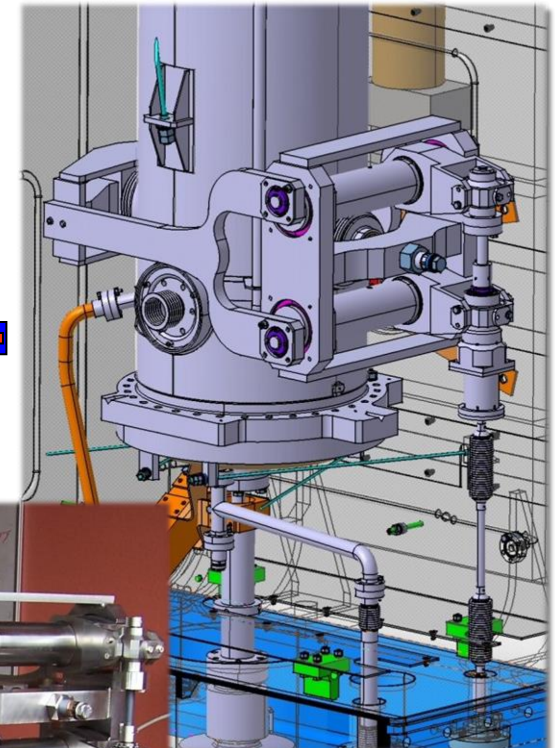




Spiral 2, "A" modules

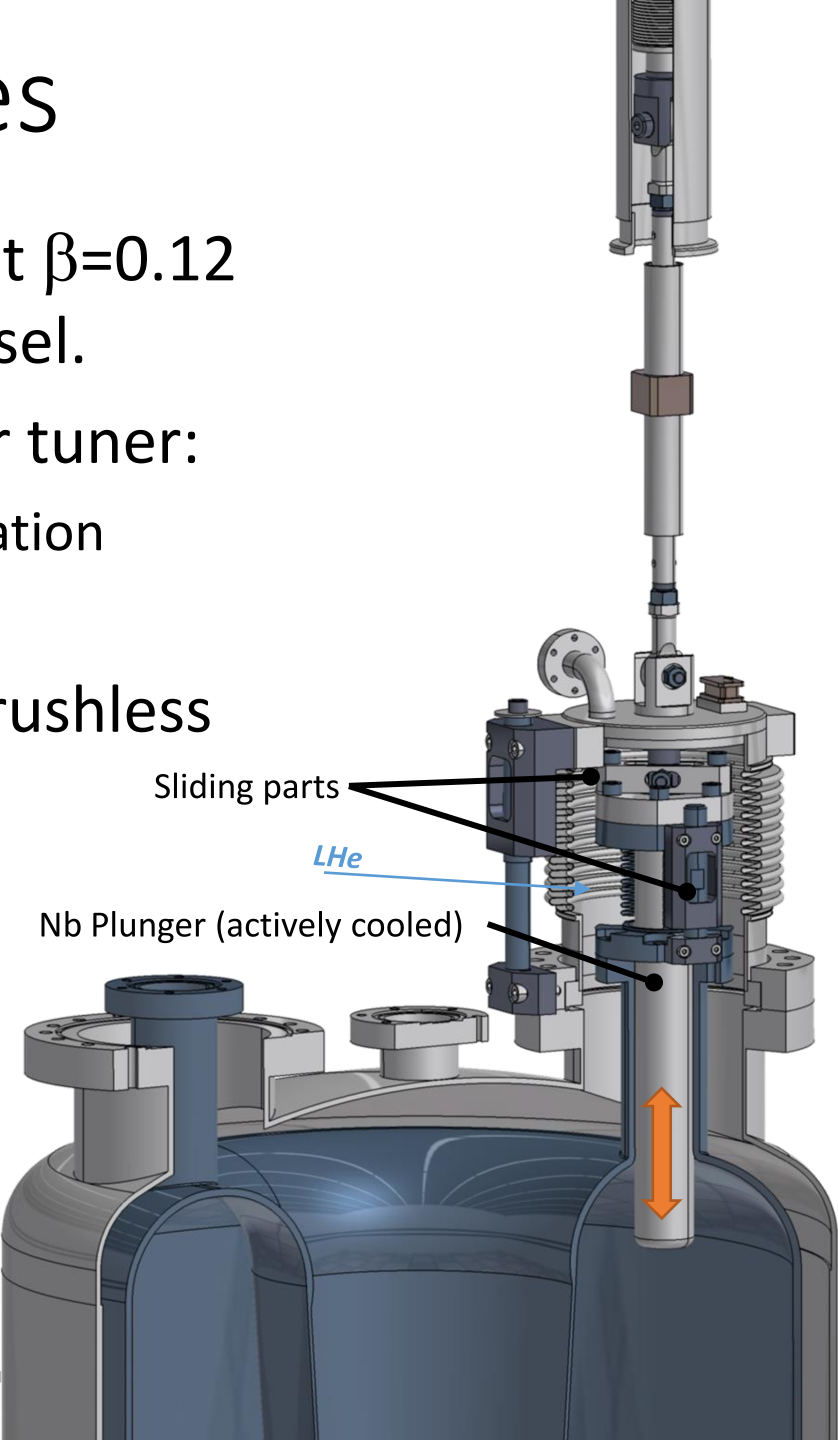
- Lower beta section from CEA, 88 MHz β=0.07 QWR, 4 K. Single cavity vessel.
- Transverse tuner mechanics inspired to CTS/Saclay-II kinematics.
  - Two lever arms with eccentric joints transform rotation into longitudinal displacement
  - Minimal longitudinal footprint.
  - Warm stepper motor
- Cavity plastic limit onset
  - Shape and position of tuner-to-cavity wall connection optimized to extend cold tuning range to 25 kHz
  - Disengagement system
  - Tuner heater to warm it up faster than the cavity
- Average results from CM cold tests:
  - 26.4 Hz/turn tuning sensitivity
  - 1.8 Hz hysteresis (4 Hz peak) by changing motor rotation every half turn



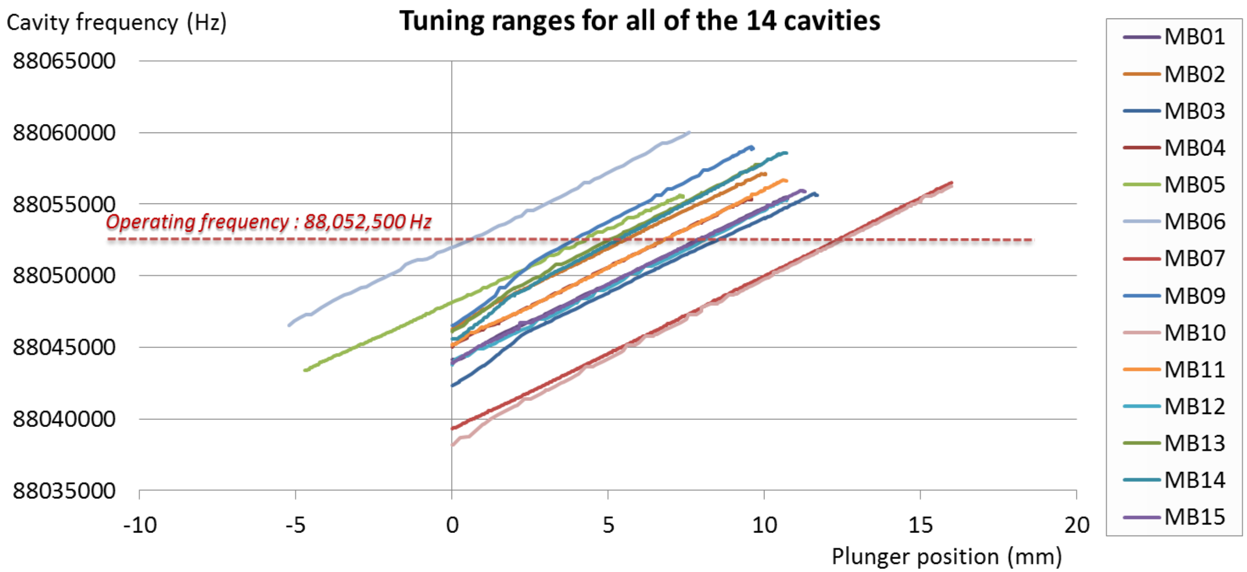


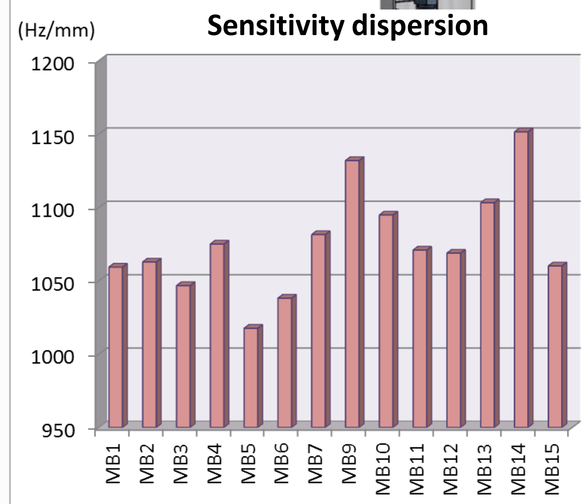
Spiral 2, “B” modules

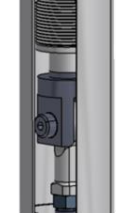
- Higher beta section from IPN at β=0.12 QWR, 4 K, two cavities per vessel.
- Hollow, SC, LHe cooled plunger tuner:
  - 20 mm diameter, 50 mm penetration
  - Up to +/-5 mm tuning range.
- Directly actuated by a warm brushless motor drive.
- Extensively demonstrated and developed along CM tests
  - Unexpected hysteresis and overshoot due to slight plunger tilting



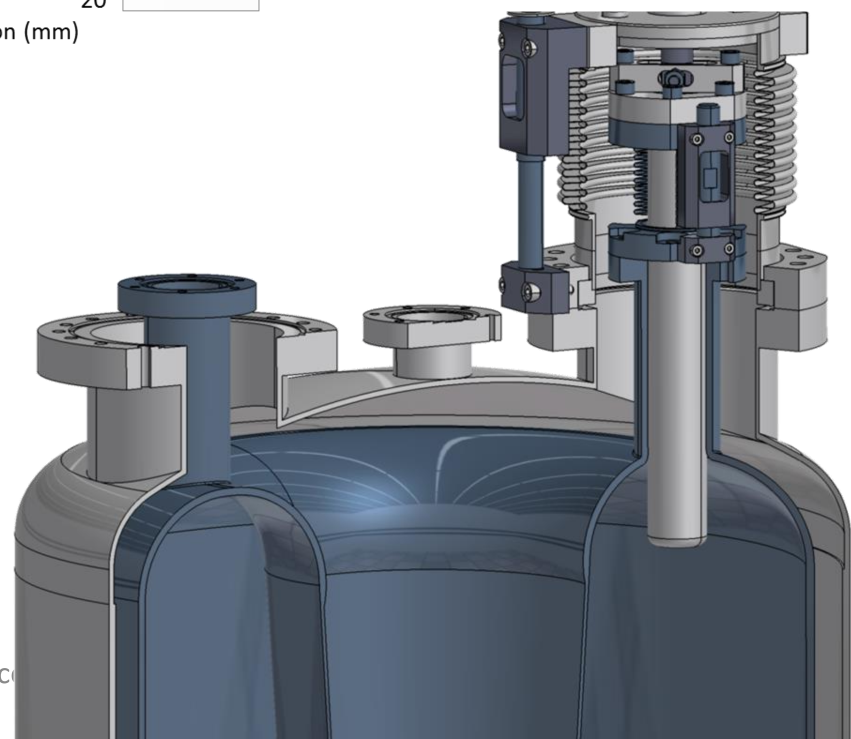
Spiral 2, “B” modules







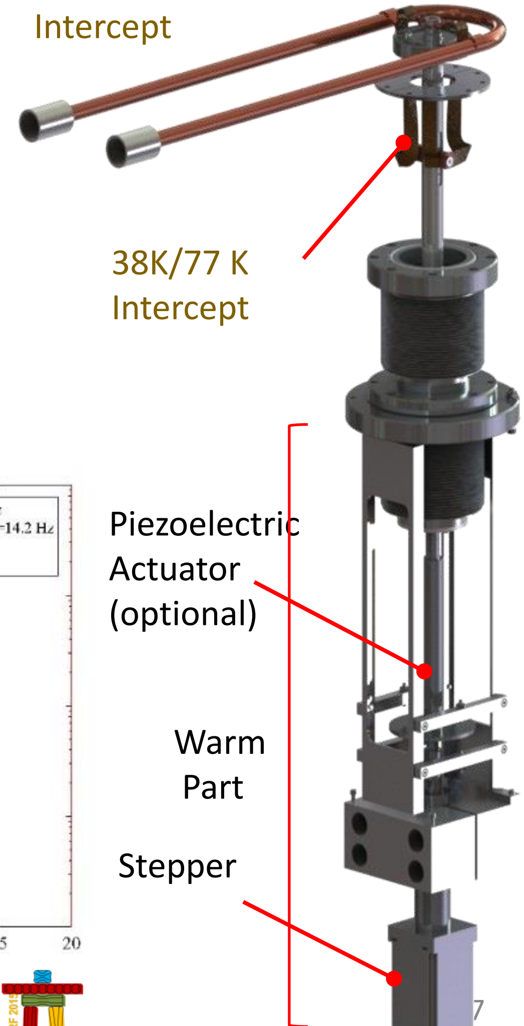
- CM test completed in Dec. 2014
  - All plunger systems up to specs: 1 kHz/mm sensitivity and 10 kHz range
  - No negative impact on cavity performances.
- Both A and B tuner types have been extensively demonstrated during single CM cold tests.
  - Further tuner results to come with linac commissioning. String assembly is ongoing.



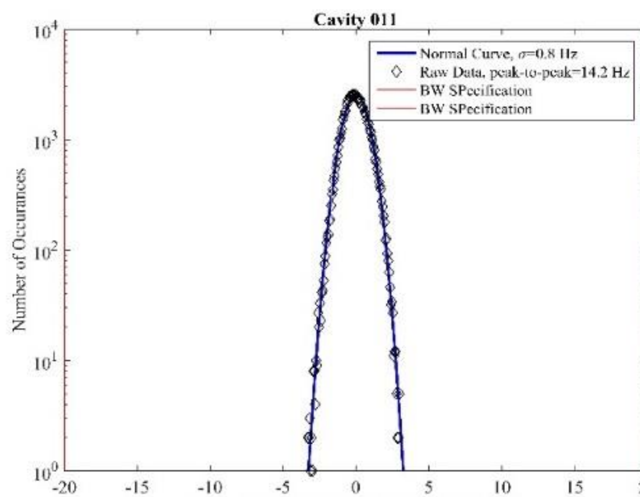
FRAA06

FRIB at MSU, QWRs

- β=0.041 and β=0.085 QWR, 80.5 MHz
- Lower plate position is directly determined by a warm stepper motor actuator
- Optional possibility of a in-series, warm fast actuator is kept for risk mitigation.
- Operations without active compensation have been validated through cold tests in ReA3 and ReA6 CM:
  - 24h run with continuous lock in ReA6 at 4K
  - FRIB specs fulfilled with margin: Eacc to 6.2 MV/m or 110% of goal value

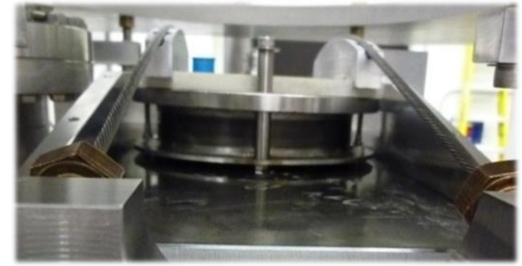


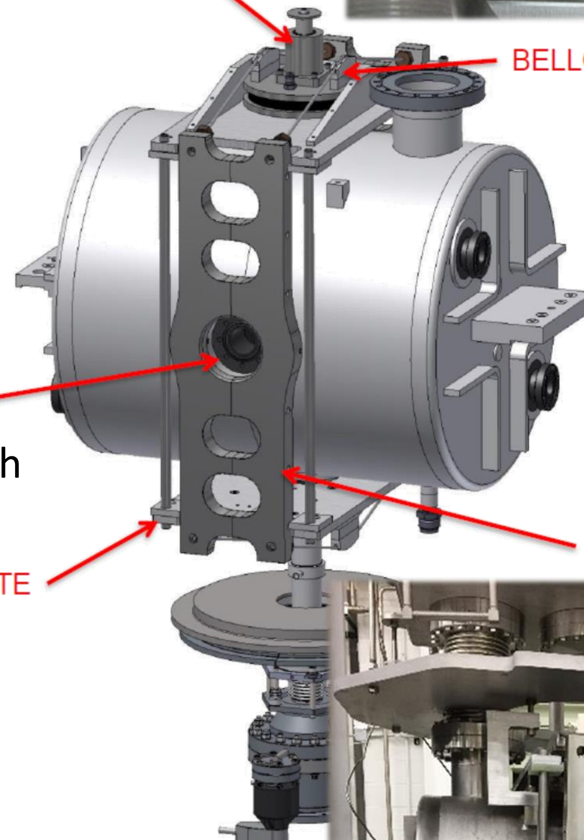
	Gradient	Detuning	
4K test	E_a (MV/m)	σ	pk-pk
Meas. QWR 1	6.2	0.8	14.2
Meas. QWR 2	6.2	0.8	22.2
FRIB goal 2 K	5.6	<2.25	<20



FRIB at MSU, HWRs

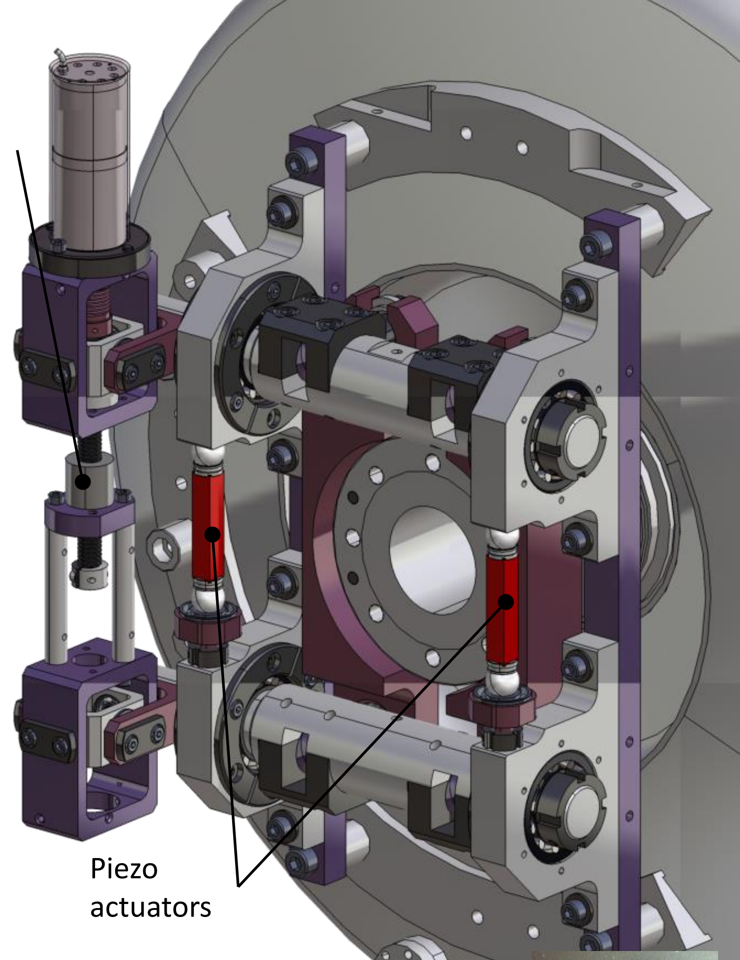
- β=0.29 and β=0.53, 322 MHz
- Initial scissor-type tuner prototype discarded in favor of a revised ANL-like pneumatic system:
  - Design finalized for 0.53 cavities
  - Split top/bottom plates and bars to allow for side mounting with power coupler already in place
  - Simpler he gas actuated bellow design with no sliding elements in place of a single copper-graphite bushing
- First positive warm test done, one planned at ANL and then a cold test will follow
- Preliminary results from prototype are satisfactory:
  - 54 kHz coarse range
  - 20 Hz/mbar tuning sensitivity
  - Tuning speed between 250 and 600 Hz/s

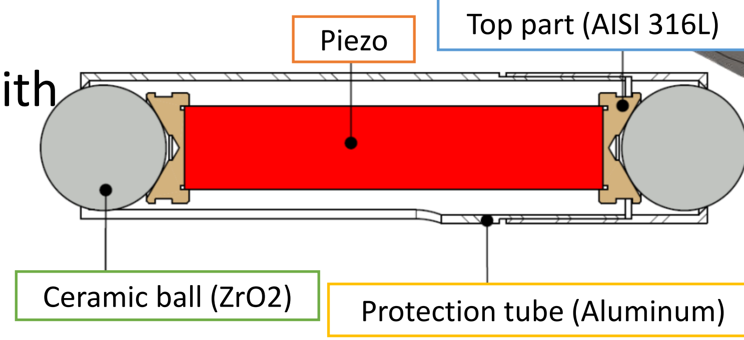




ESS Spokes

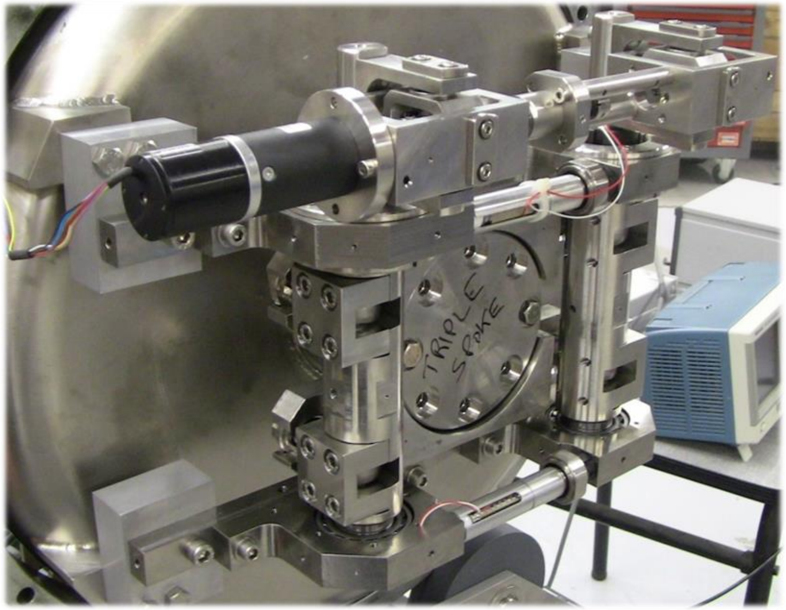
- β=0.50 section, 352 MHz double spoke from IPN
  - 100 kHz/mm and 20 kN/mm in the longitudinal tuning direction
- Pulsed RF operations : 2,86 ms at 14 Hz repetition rate.
- Tuner mechanics inspired to CTS/Saclay-II and installed at beam-port
  - Cold stepper motor with dry-lubricated ball-screw system
  - Two cold piezo installed in between lever arm joints
  - Special piezo encapsulation with ceramic spherical interfaces designed to protect stack and ease assembly

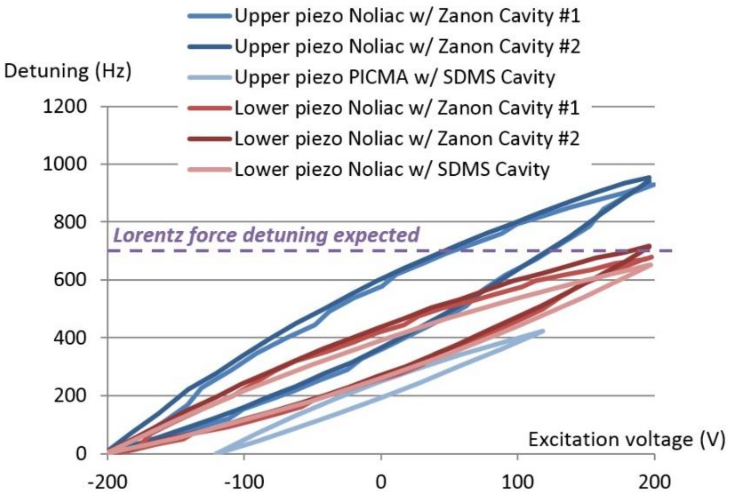


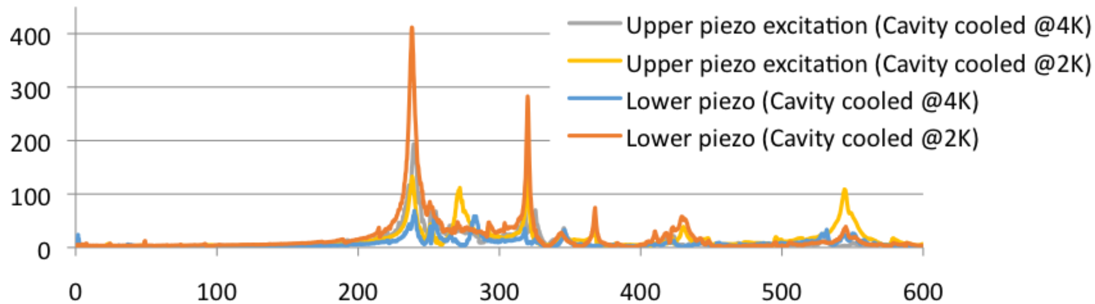


ESS Spokes

- Cold tests recently performed
  - 3 cavity prototypes
  - 2 different piezo models
- Coarse and fine tuning range as expected
  - About 170 kHz coarse range
  - piezo closer to motor is about 33% more efficient for kinematic reasons
  - Fully bipolar piezo operation proven. Piezo temperature measured in the range 20-30 K
- Upcoming developments:
  - Further evaluate the use of longer piezo up to 90 mm to lower voltage level and increase stroke
  - Include a mechanical disengagement system
  - Explore the viability of a plunger insertion tuner

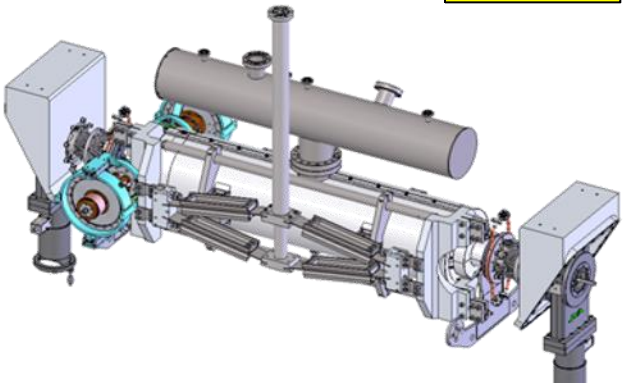


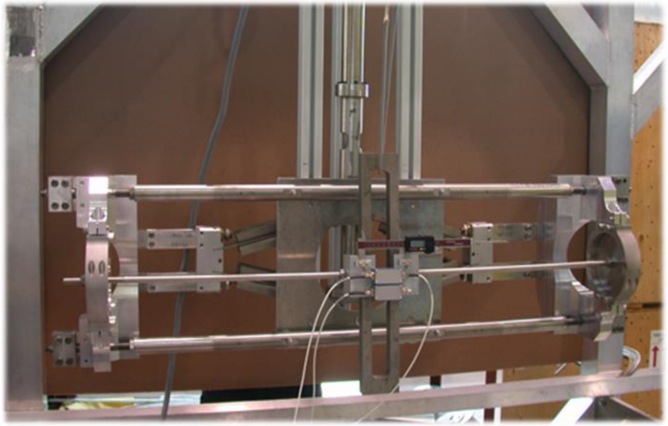


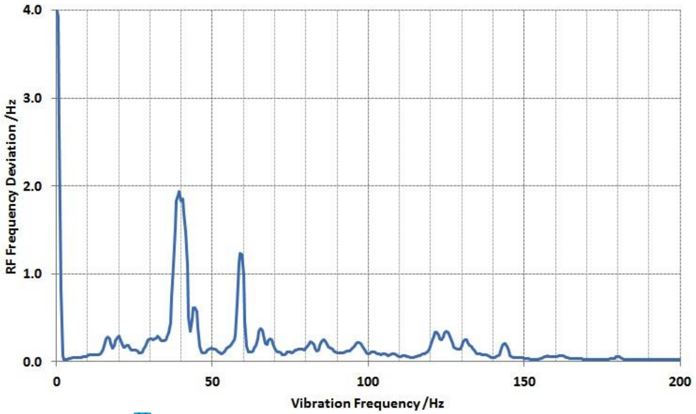


ARIEL e-linac, TRIUMF

- 1.3 GHz TESLA type cavities, revisited for intense CW operations
- Scissor-type tuner:
  - The original cold flexible leverage from JLAB CEBAF, adapted to TESLA cavity
  - Titanium flex joints connecting pivot plates, no rotating axles
  - Warm driving motor updated to the rotary servo-motor with ball-screw from ISAC-II
  - Successfully test-benched at RT with a cavity mock-up
- Initial cold tests results
  - 400 kHz tuning range, exceeding specs
  - Sound cavity phase lock
  - Viable MP level, also thanks to large cavity BW and stable CM operations at 2 K
  - MP spectrum at ICM cold test in the plot
- Detailed tuner-related results are going to come later in 2015 in the framework of ICM&ACM commissioning.

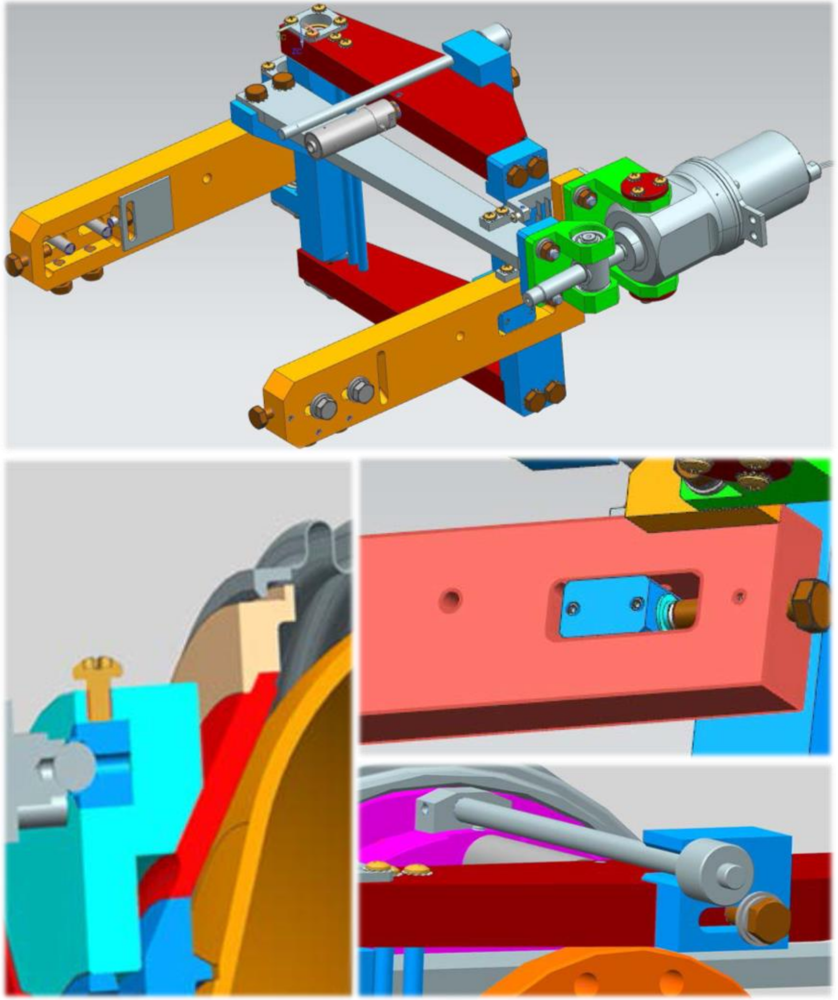






LCLS-II at SLAC

- CW linac with 1.3 GHz resonators, technically identical to E-XFEL ones
- Novel tuning system designed by FNAL, baseline is E-XFEL double lever with key modifications:
  - Higher mechanical reduction ratio (21.5) and 450 kHz range
  - “push” action in place of “pull”
  - Cold actuators installed but designed to be accessible through a dedicated port on the vessel
  - Adjusting screw introduced to release cavity spring-back force
  - Safety bars
  - Stiffer tuner ring design
  - Two encapsulated piezo actuators directly coupled to cavity
  - Planetary motor gearbox with titanium rod



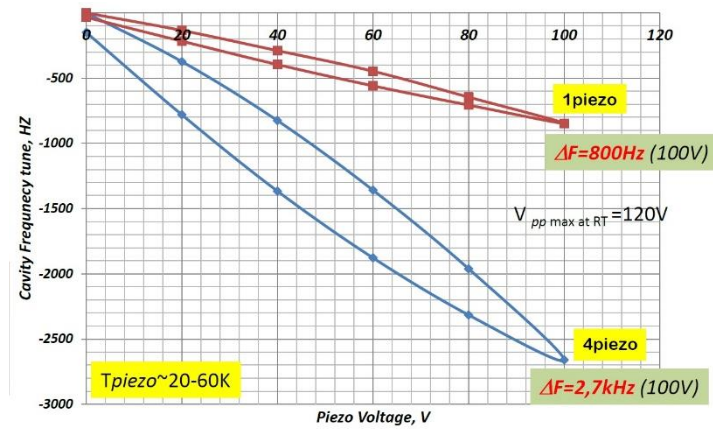
LCLS-II at SLAC

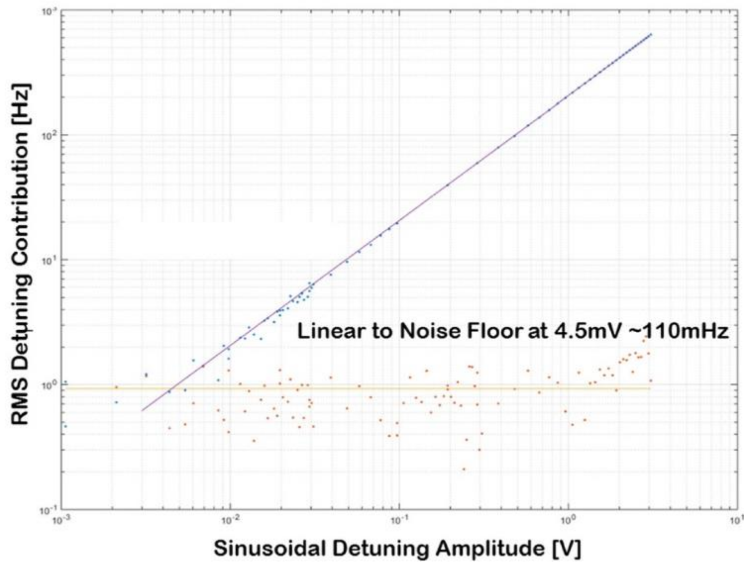
THPB064

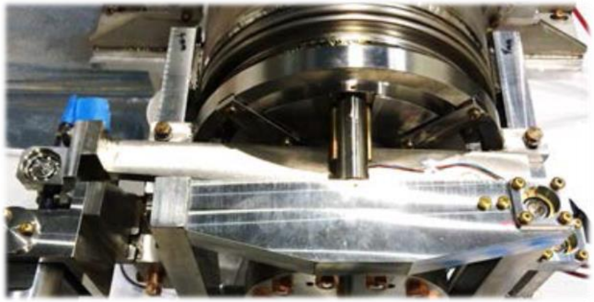
THPB062

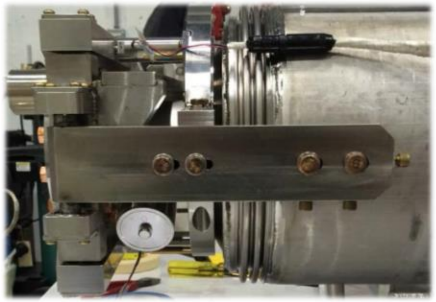
THPB065

- Several cold tests already done in 2014 and 2015, HTS cryostat at FNAL upgraded for CW RF.
  - noisy BG, up 100 Hz peak MP
- Both static and dynamic performances were met
  - 1.4 Hz/step with good linearity over full range
  - DC stroke with both piezo higher than 3 kHz with two 18x2 mm stacks
  - Piezo tuning resolution measured to be well below 1 Hz with an AM 10 Hz drive signal
- Design is mature and part procurement for first 16 units already started



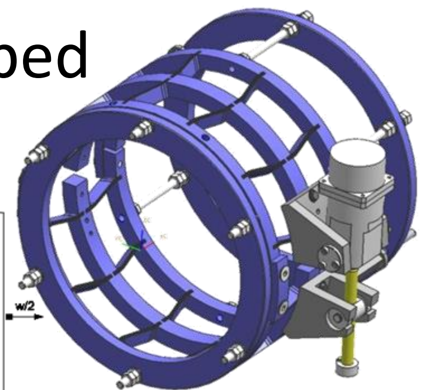


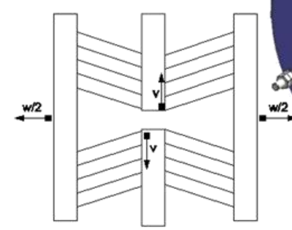


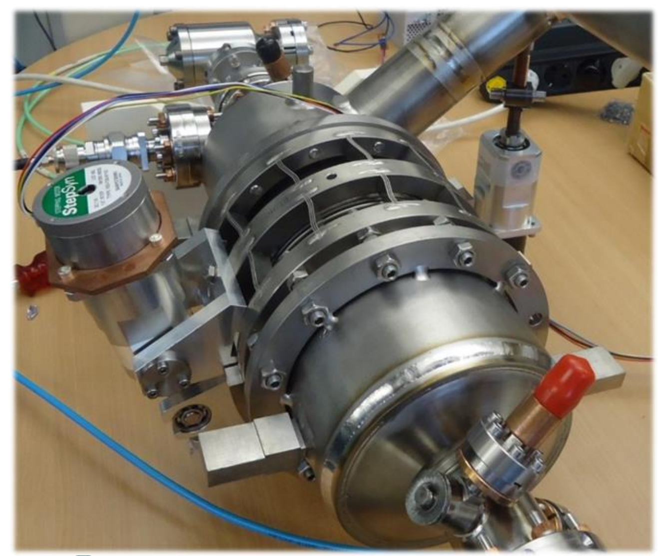


E-XFEL, 3rd harmonic

- 3H module with 8 3.9 GHz cavities from INFN Milano for E-XFEL injector
- Cold tuner inspired by Coaxial Blade developed for ILC cavities
  - No fast piezo action required due to moderate gradient at 15 MV/m and stiff cavity, about 5,4 kN/mm longitudinally
  - Already extensively validated at RT and cleared for series production in 2013. 20 units delivered by the end of 2014.





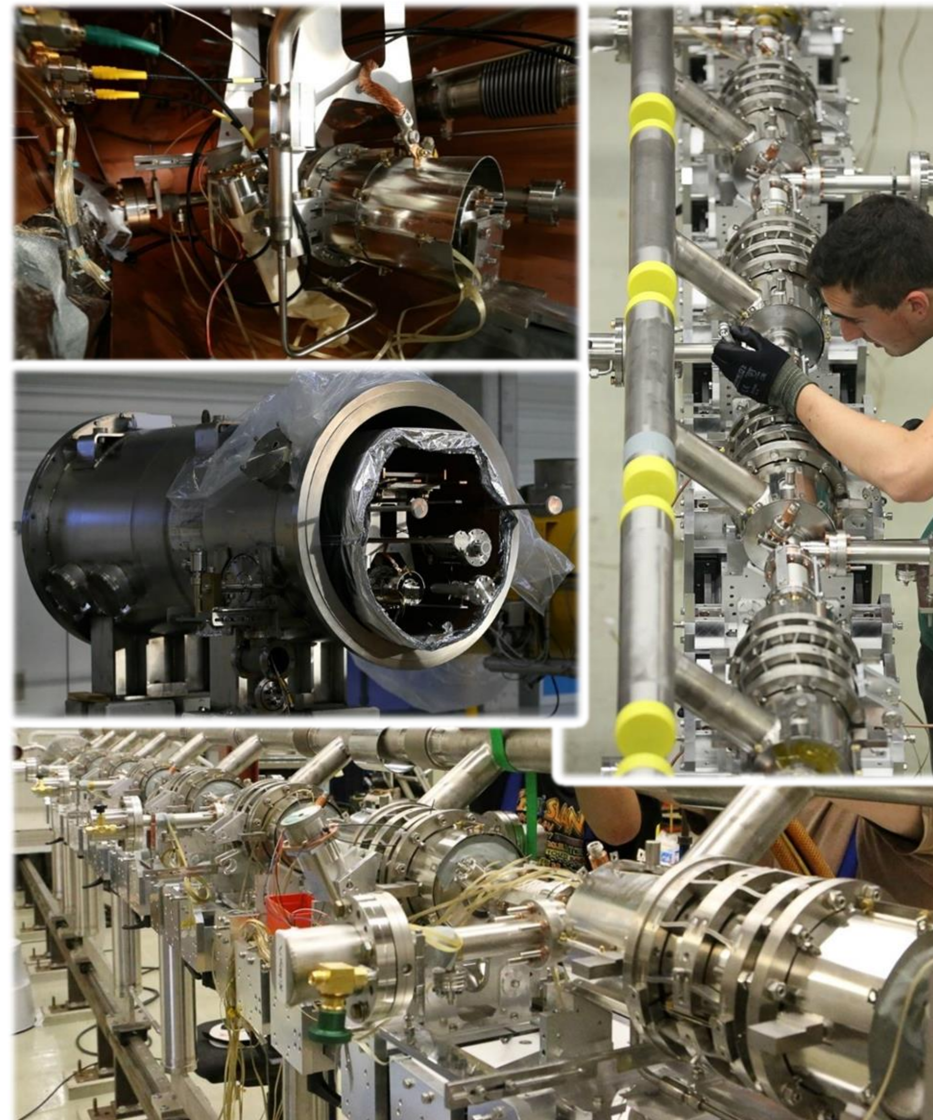


E-XFEL, 3rd harmonic

MOPB076

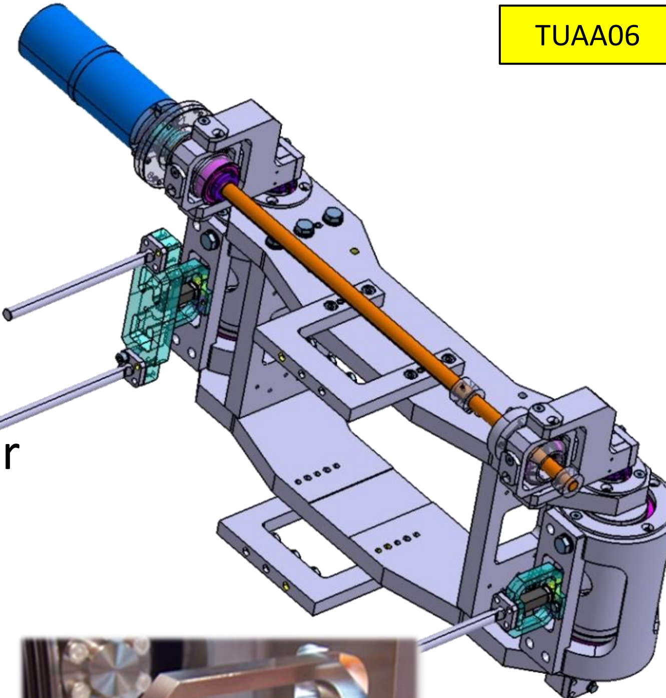
TUPB018

- Horizontal cold test on a dressed cavity performed in March 2015
  - AMTF at DESY, cave #1 used with special cryo-adapter from BINP
  - Cold tuning range of 1 MHz (plastic limit) reached with margin
  - Tuning sensitivity not higher than 2.4 MHz/step
  - Standard 1.3 GHz main linac motor unit confirmed to be compatible. 240 ksteps to goal, 70400 steps/turn configuration.
- 3H cavity string assembly started in June 2015 at DESY
  - Tuner functionalities cross-checked after installation with limited motor shift.
- Further results from E-XFEL injector commissioning expected to commence before the end of 2015

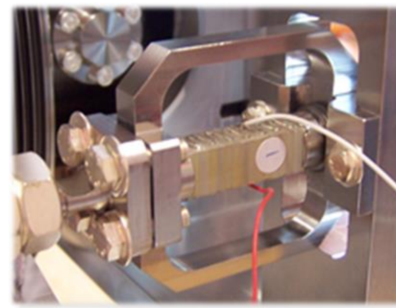


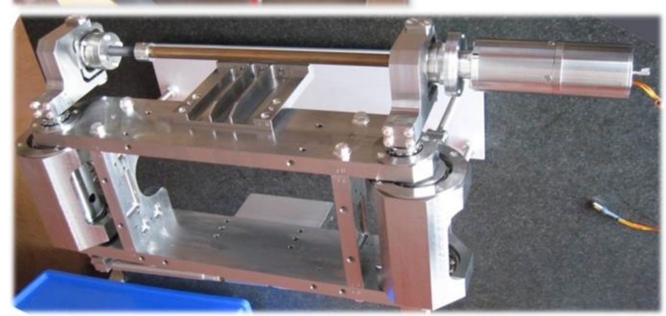
TUAA06

SPL and ESS, elliptical



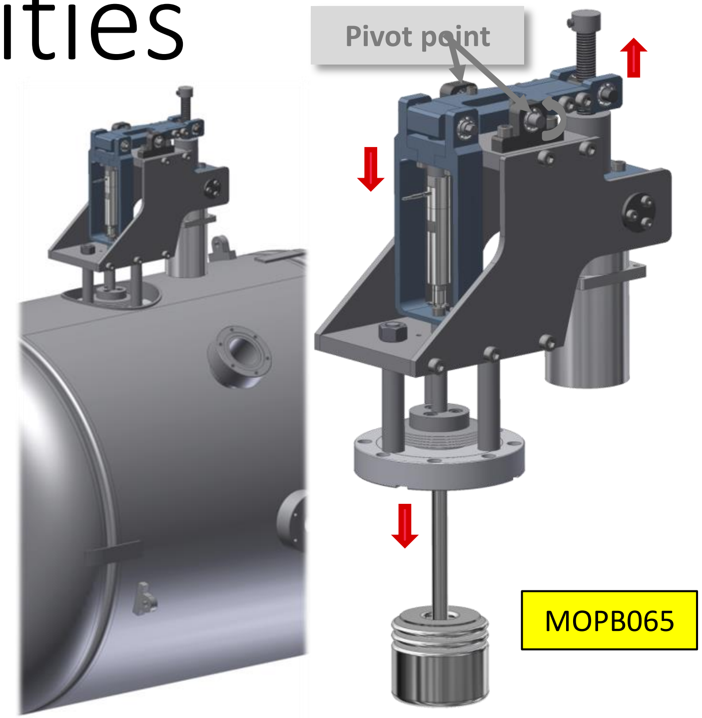
- Design activity by CEA, IN2P3, CERN, INFN and others on high-beta, elliptical, multi-cell cavity for protons.
- Common tuner base developed from CTS/Saclay-II, design is finalized and is ready for procurement
  - cold stepper motor with planetary gearbox
  - Piezo hosted by a stiff (10x cavity) frame and installed at the tuner to tank connection
- SPL β=1 5-cell, 704 MHz
  - A first series of tuner already produced and test benched at RT with a copper cavity
  - The first Nb cavity integrated in its helium tank is now available so a more realistic tuning system validation is expected in the near future
- ESS β=0.67, 6-cell and β=0.86, 5-cell, 704 MHz
  - Minor modifications to SPL design, mainly in the beam tube region
  - Two piezo frame with single stack installed for redundancy, one on each side of the beam tube.
  - 600 kHz expected tuning range

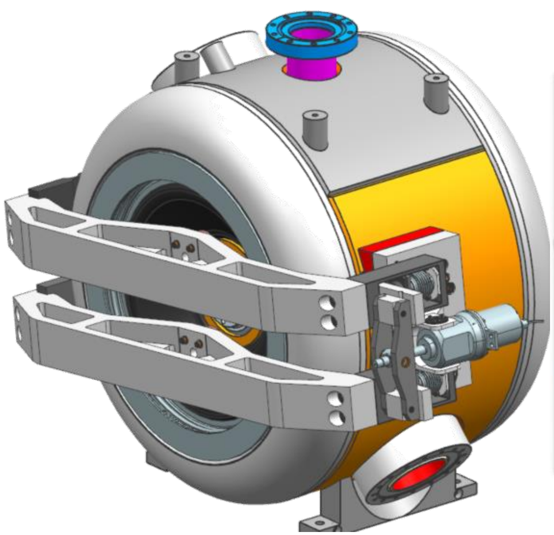


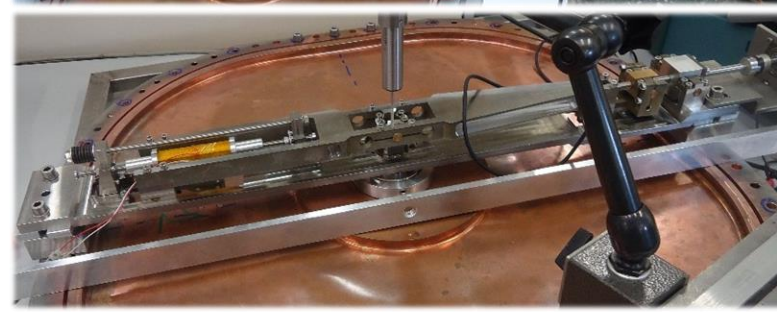


Further ongoing activities

- 325 MHz CH-Cavity at IAP-Frankfurt
  - Cold test successful in nominal operating conditions recently done at 4 K and 2 K
  - About -130 kHz/mm coarse and -150 Hz/μm fine tuning sensitivity
- 80 MHz PIAVE SC RFQs at INFN-LNL
  - Extremely slim lever kinematics with warm motors and featuring the longest piezo actuators so far in SRF projects: 140 mm with bonded hemispherical heads.
  - Prototype successfully cold tested in May 2015 with 70 mm stack, now in procurement phase.
- 325 MHz SSR FOR PIP-II AT FNAL
  - Novel double lever scheme with different reduction ratio between motor and piezo. Actuators accessible for removal.
  - Validated at cold in STC at FNAL







Acknowledgements

Thanks all those that have been involved in the completion of these review for having promptly provided information, pictures and results from each project and laboratory.

This was not meant to be a comprehensive listing of all existing tuning systems, just few topical examples have been highlighted.

K. Saito, S. Starck and colleagues at FRIB, MSU

G. Devanz, P. Bosland, O. Napoly, C. Madec at CEA

N. Gandolfo at IPN/IRFU

L. Lilje at DESY

Z. Yao and colleagues at TRIUMF

Y. Pischalnikov and colleagues at FNAL

A. Nassiri, Z. Conway and colleagues at ANL

All the colleagues in INFN-Milano

Tuning SRF structures

- Tasks:
  - Drive and keep cold cavity at goal frequency against production spread and static errors. Detune cavity if needed.
  - Compensate for slow, long-term drifts during operation
  - Compensate for superimposed, dynamical tune disturbances
- Challenging:
  - involves different disciplines simultaneously: mechanics, RF, cryogenics, controls and electronics.
- As of today, a cavity in operation at the given set-points requires a mix of:
  - LLRF field control
  - Coarse and micrometer-range tuning mechanism
  - Passive and by-design damping strategies
- Few general considerations impacting tuner design:
  - Type, Deformation vs. Insertion …
  - RF, CW vs. Pulsed …
  - Large cavity QLoaded vs. Large bandwidth …
  - Actuators accessibility vs. Heat load …
  - Active microphonics compensation, Yes vs. No …
  - Tuner position, At beam tube vs. Around …

Conclusion

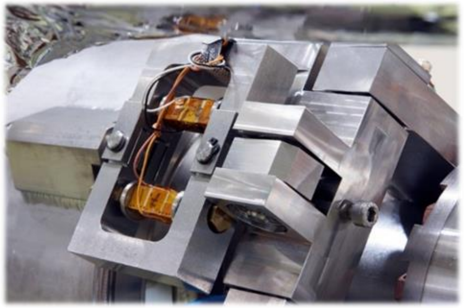
- Looking through:
  - a general attitude seems to stand in favour of the safest use of consolidated tuning designs in place of totally novel schemes.
  - The quality of initial tuner design is as good as the ability in introducing workaround solutions to unexpected issues, a reaction that may even extend up to a radical change.
  - Installations of cold actuators are quickly growing in number, thus moving the spotlight onto reliability for the next years.
  - Larger projects are going to be crucial to prove that such a complex system as a cold tuner is able to withstand the challenge of mass-scale production foreseen for next-gen projects as the ILC.

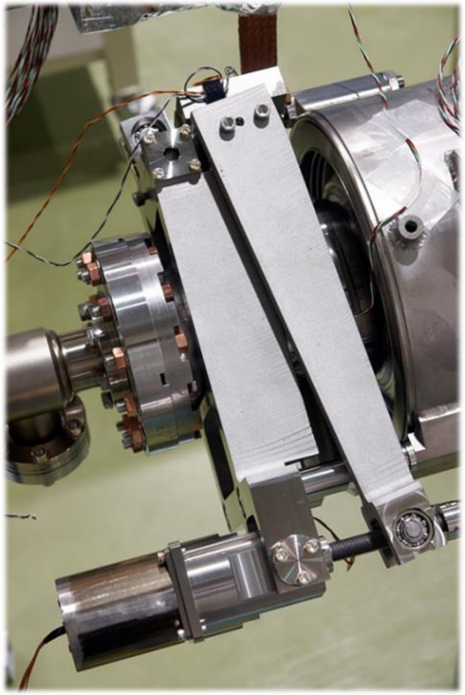
FRAA02

MOAA02

E-XFEL, main linac

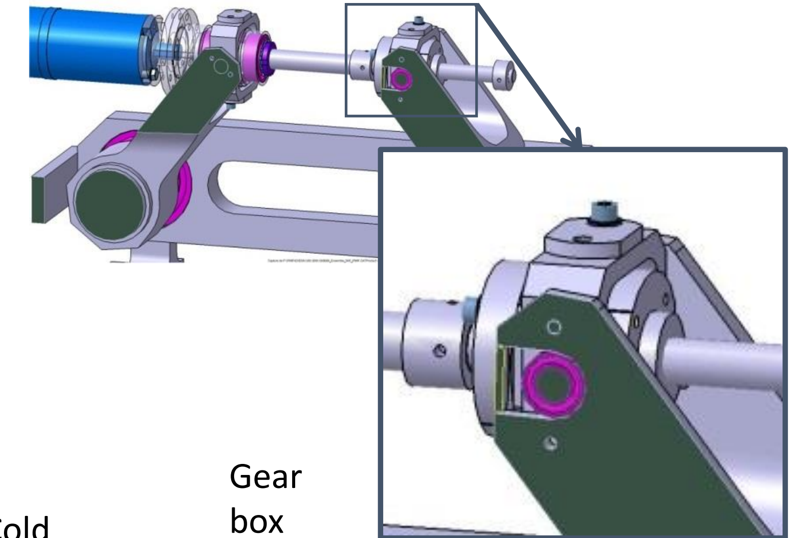
- 1.3 GHz TESLA type cavities, pulsed RF with 1 ms at 10 Hz rate.
- Lateral tuner with double asymmetric lever system and cold actuators: stepper motor with HD and two piezo stack in a single frame.
- A large-scale tuner assembly and validation procedure has been established:
  - So far, with XM61 under assembly out of 101 and about 500 tuner installed, successful
  - Greatest contribution from pre-assembly controls and resources:
    - Agreements with manufacturer
    - Detailed assembly instructions
    - Only minor non-conformities detected afterwards
  - As of today, with 55 cryomodules cold-tested, all modules exhibited a fully functional tuning system

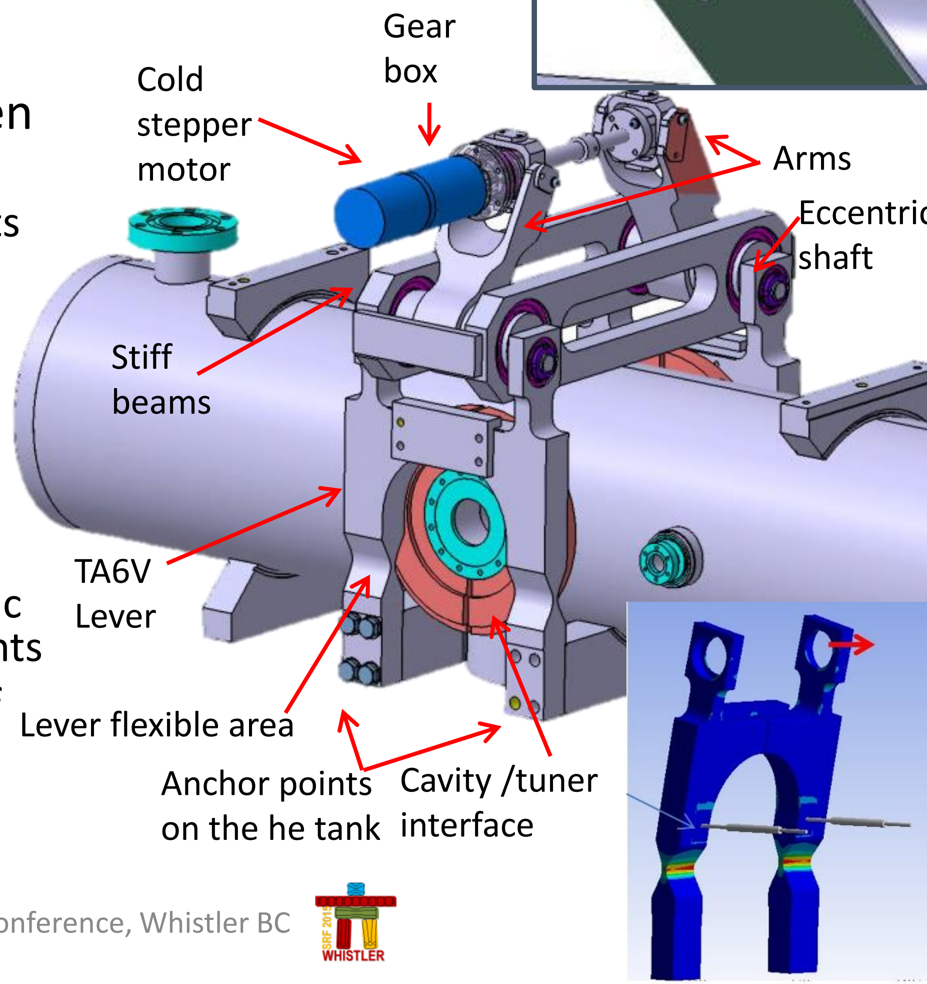




IFMIF/LIPAc

- 175 MHz, β=0.097 QWR for IFMIF LIPAc demonstrator
- Cavity central region updated, now hosting a deformation-type tuner.
- The CTS/Saclay-II kinematics , initially designed by CEA to drive a vertical tuning membrane, has been revised:
  - A squeezing action at the beam ports is generated by titanium arms with flexible hinges
  - 2 mm lever top stroke generates 0.3 mm cavity displacement
  - The bulk coupler port at the bottom determines an asymmetric strain
  - A disengagement systems has been introduced to save cavity from plastic deformation during thermal transients
- Design is finalized. Procurement of parts is in progress.





Appendix – An overview

	ATLAS QWR	FRIB QWR	FRIB HWR	IFMIF HWR	SPIRAL2 A QWR	SPIRAL2 B QWR	ESS SPOKE	ARIEL ELL.	XFEL ELL.	XFEL 3H ELL.	LCLS-II ELL.	ESS ELL.	SPL ELL.
Deformation - Insertion	Pneumatic	Moving plate	Pneumatic	Lever + eccentric	Lever + eccentric	Plunger	Lever + eccentric	Scissor	Lever	Coaxial Blade	Lever	Lever + eccentric	Lever + eccentric
RF: CW Pulsed	CW	CW	CW	CW	CW	CW	Pulsed	CW	Pulsed	Pulsed	CW	Pulsed	Pulsed
Actuators: Cold Warm	Cold	Warm	Cold	Cold	Warm	Warm	Cold	Warm	Cold	Cold	Cold access.	Cold	Cold
Fast actuators: Yes No	Optional	Optional	No	No	No	No	Yes	No	Yes	No	Yes	Yes	Yes
Active MP comp: Yes No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
Tuner Position	Across BP	Direct	Across BP	Across BP	Across BP trasv.	Direct	At BP	Across BP	At BP	Coaxial	At BP	At BP	At BP