ILC-HiGrade Scientific and Annual Meeting

LAL, Paris, March 6th 2009

WP8 - Tuners Report

Rocco Paparella
INFN Milano - LASA

On behalf of LASA team: **C. Pagani, A. Bosotti, R. Paparella and N. Panzeri**

Outline of the talk

Brief historical review

- The Superstructures Blade Tuner

The ILC Blade Tuner prototype – “Slim”

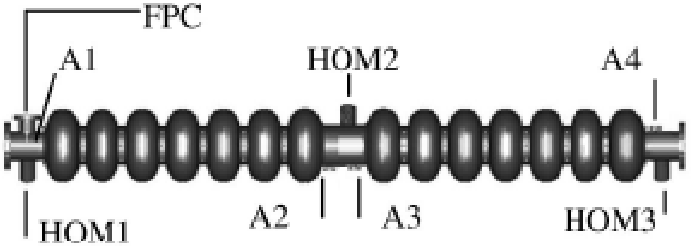
- Tuner design and tuning actions
- Cold tests of the stainless steel prototype at DESY and BESSY

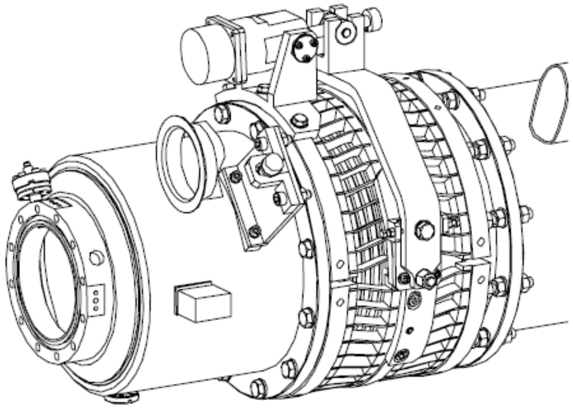
The Revised ILC Blade Tuner

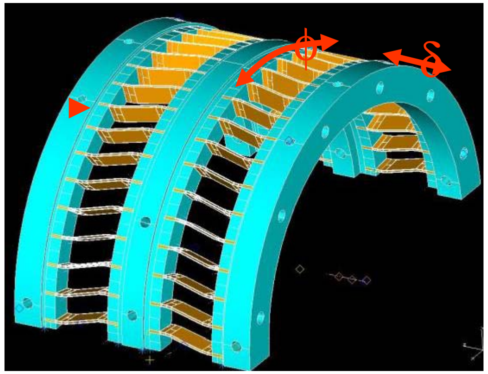
- Rationales
- Expected performances from FEM analyses: load cases and limit loads, warm tests as expected

Tuner position, plug compatibility, end groups

The Superstructure Blade Tuner







Concept: through thin "blades" transform the rotation of the 2 center ring halves in a longitudinal axial motion that changes the cavity frequency modifying its length.

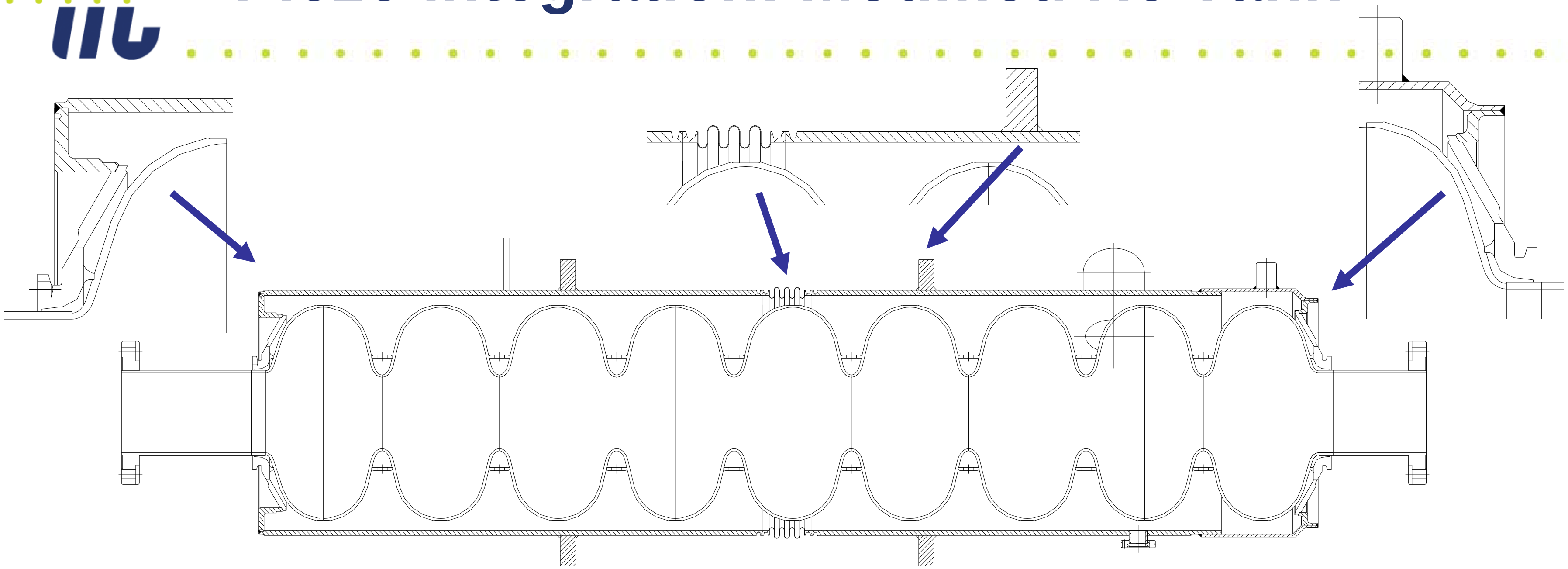
Standard motor and harmonic drive

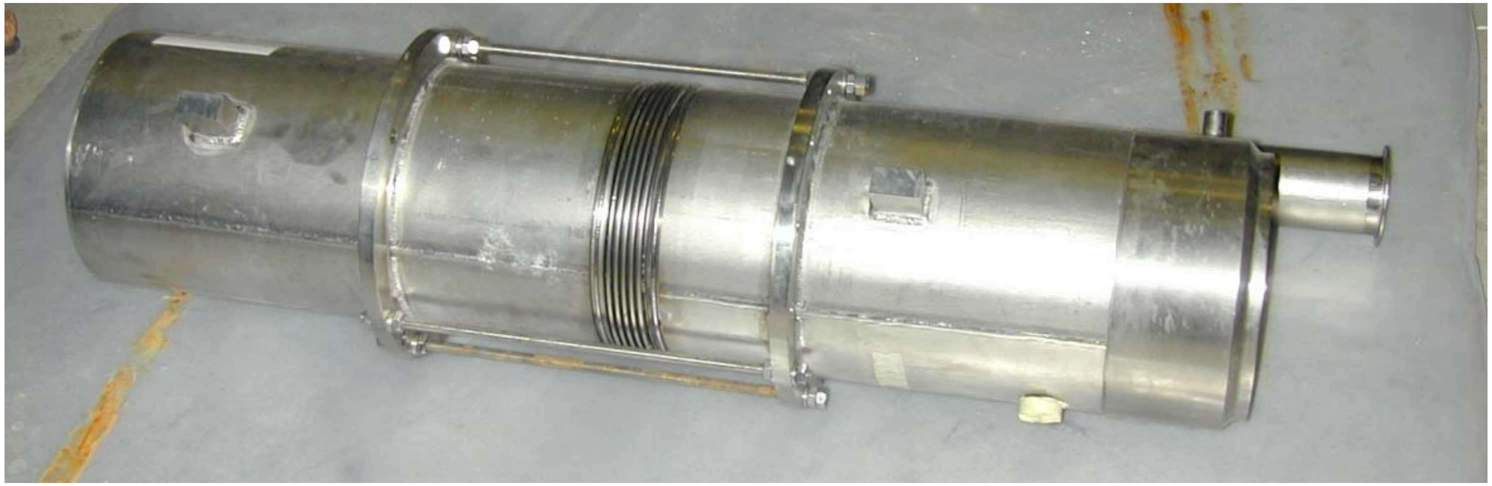
Lever arm designed by H.-B. Peters (DESY)

Comments and Results

- **Just slow tuning mechanism**, **no piezo-actuators installed**
- Superstructures performed very well at 15 MV/m
- Each of the four blade tuners smoothly tuned the respective cavity to the nominal frequency
- Each cavity was maintained tuned during operation
  - Correction threshold set at few degrees (few Hz)
  - Data available on TTF database
  - Each motor step produces a **0.4 Hz** frequency variation that is induced by a **1.2 nm** cavity length variation (**no irregularities observed because of rollers**)
- Each of the two cavities of a superstructure were corrected independently with the same number of steps to maintain the critical field balance of the π-0 superstructure mode

Piezo integration: Modified He Tank





Motivation and consequences

Motivation

- build **2 helium vessel** to test at DESY and Fermilab 2 of the **existing superstructure** blade tuner with 2 parallel piezo-actuators:
  - in series with the tuning mechanism
  - positioned on the mid plane

Consequences

- Because of the very heavy superstructure tuning mechanism one pad couple was moved closer to the ring supporting the tuner weight.
- A special adaptation element was designed to adapt the new pad position to the standard (TTF-FLASH-XFEL) shape spacing
- A simple adaptation at the end cone region, as for superstructure, was done given that longitudinal stiffness is not so critical.

Real life

- No sufficient priority on ILC and no testing slot available up to 2007 neither at DESY not at Fermilab. **New Blade Tuner**

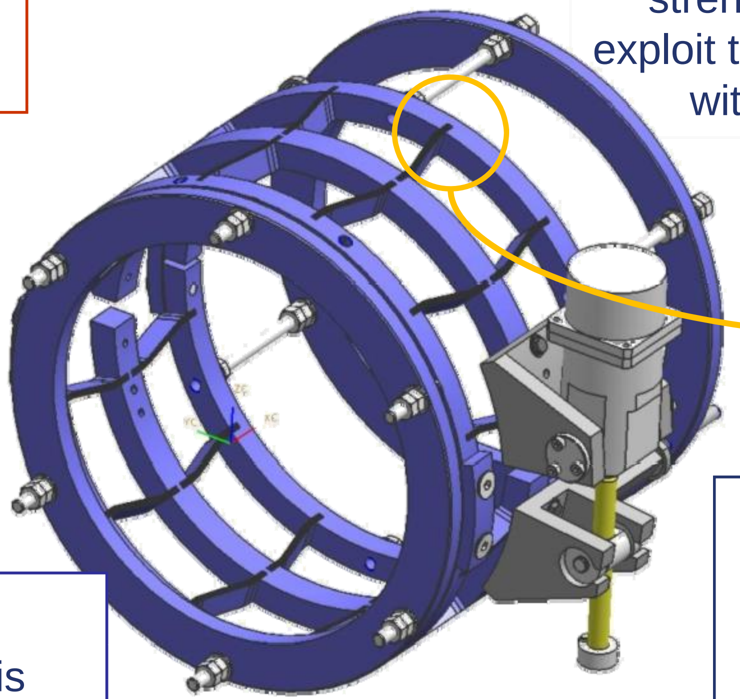
Blade Tuner “Slim” Prototype

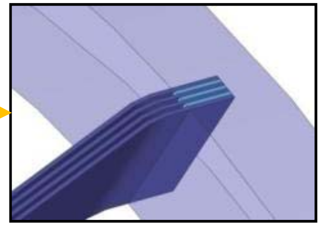
Lighter

The redesign of rings allowed an important **weight reduction** (about 40%) maintaining the full symmetry with collinear blades.

Ready for future SS tank

The tuner can be **built both with titanium or stainless steel rings**. We used a high strength alloy for blades to exploit the full tuning capabilities without plastic strains.





Cheaper

The new geometry and mechanism lead to an **important reduction of costs**.

Wider tuning range

The different blade geometry adopted **improve the slow tuning capabilities** to more than 1.5mm at the cavity level.

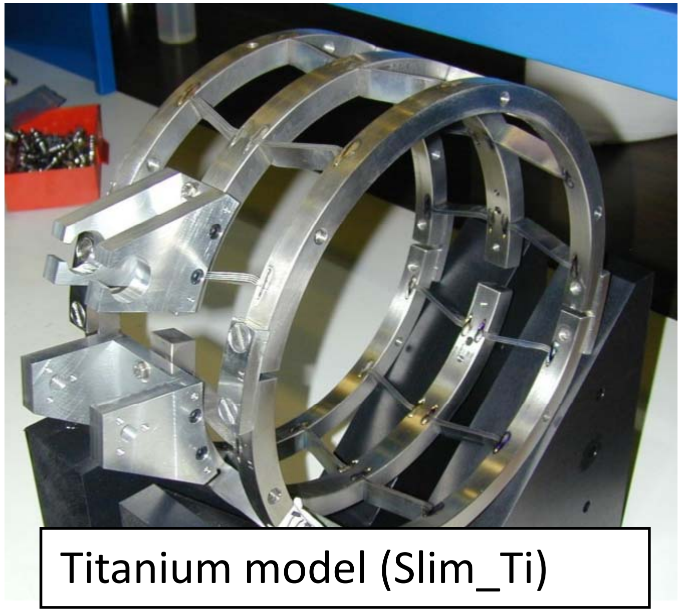
New driving mechanism

The new driving mechanism is simpler, **cheaper and more compact**, simplifying the installation of an external **magnetic shield**.

Blade Tuner prototype cold tests

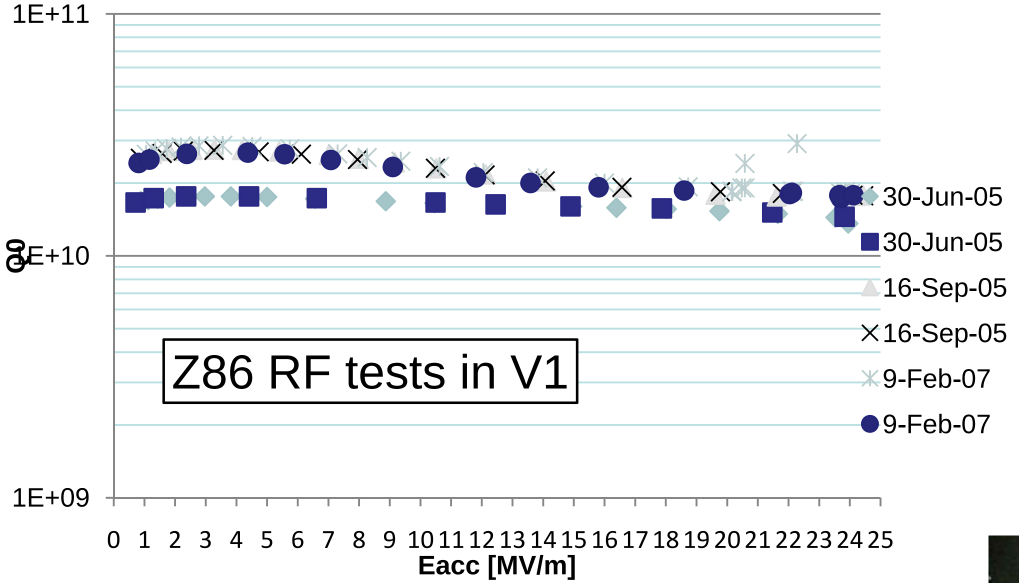
- **The Stainless Steel + INCONEL prototype has been tested at cold:**
- **Sept. 2007 in the CHECHIA** horizontal cryostat, DESY
  - Installed on the **Z86 TESLA cavity** equipped with a standard modified He vessel
  - Equipped with a standard TTF unit: **Sanyo stepper motor + Harmonic Drive gear**
  - **2 Noliac 40 mm** standard piezoelectric actuator installed
- **Feb. 2008 in the HoBiCaT** horizontal cryostat, BESSY
  - The same assembly but equipped with a prototype of a possible alternative driving unit: **Phytron stepper motor + Planetary Gear**

Stainless Steel + Inconel model (Slim_SS)



Titanium model (Slim_Ti)

Z86 TESLA cavity



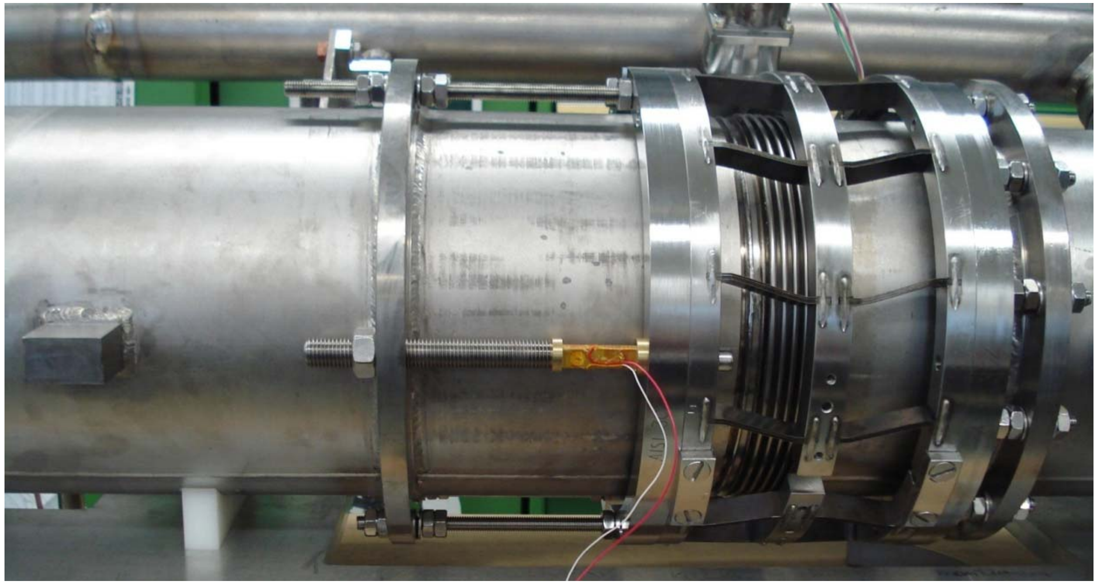
The tuner has been installed on the **Z86 TTF cavity** (24 MV/m best E_{acc}) using a "TTF standard" **modified helium tank**, with the insertion of a central bellow to allow the coaxial tuning operation

Z86 integrated in the helium tank at DESY

Z86 during the EB Welding at Lufthansa

Test setup at CHECHIA - DESY

- Blade Tuner cold tests on September 2007
  - Stainless steel + Inconel Blade Tuner
  - 40 mm Noliac piezo (10 x10 mm^2)
  - Sanyo-Denki stepper motor, 200 steps/turn
  - HD drive unit, 1:88 reduction ratio
  - therefore 17600 steps each spindle turn (CuBe spindle screw, 1.5 mm/turn) **~ 10 nm/step**



Test setup at HoBiCat - BESSY

- Blade Tuner cold tests, February and April 2008
  - Stainless steel + Inconel Blade Tuner (same as CHECHIA test)
  - 40 mm Noliac piezo (same as CHECHIA test)
  - Phytron stepper motor, 200 steps/turn
  - Phytron VGPL planetary gear, 1:100 reduction ratio
  - therefore 20000 steps each spindle turn (CuBe spindle screw, 1.5 mm/turn)

< 10 nm/step

HoBiCaT at BESSY

Considerations about friction

Superstructure Test setup

Ti pad on rolling needles (Cry 3), 40 kg preload force, T = 77 K:

- Static friction coefficient : **0.0043**
- Dynamic friction coefficient : **0.0022**

D. Barni, M. Castelnuovo, M. Fusetti, C. Pagani and G. Varisco
FRICTION MEASUREMENTS FOR SC CAVITY SLIDING FIXTURES IN LONG CRYOSTATS
Advances in Cryogenic Engineering, **Vol. 45A**, Plenum Publishers, 2000, 905-911

CHECHIA setup

PTFE Teflon on Titanium

- Static friction coefficient : **0.17** (40 times larger than Type 3)

Friction Data Guide (Linden, NJ: General Magnaplate Corp., 1988

HoBiCat setup

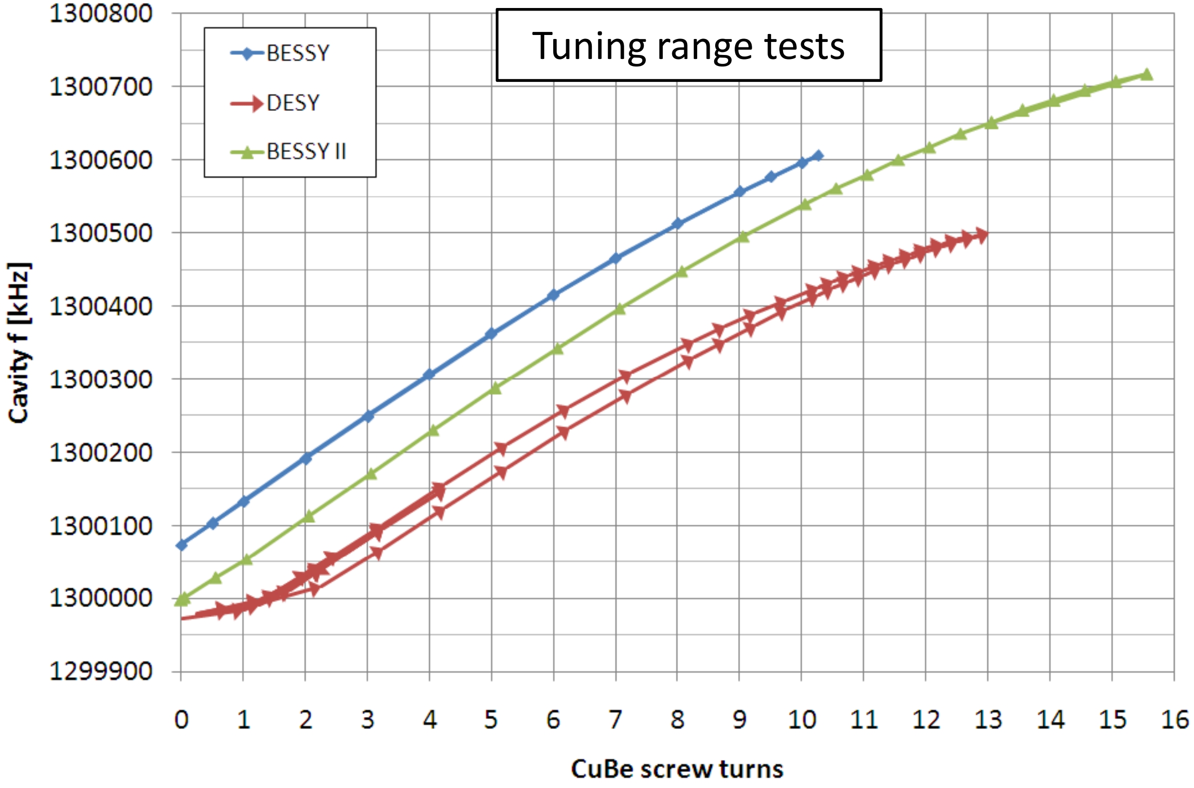
PTFE Teflon on Steel

- Static friction coefficient : **0.04** (9 times larger than Type 3)

Friction Data Guide (Linden, NJ: General Magnaplate Corp., 1988

Tuning range

600 kHz tuning range has been confirmed with margin.
The hysteresis has been almost cancelled.



Mechanical hysteresis almost cancelled over the full range after a few cycling

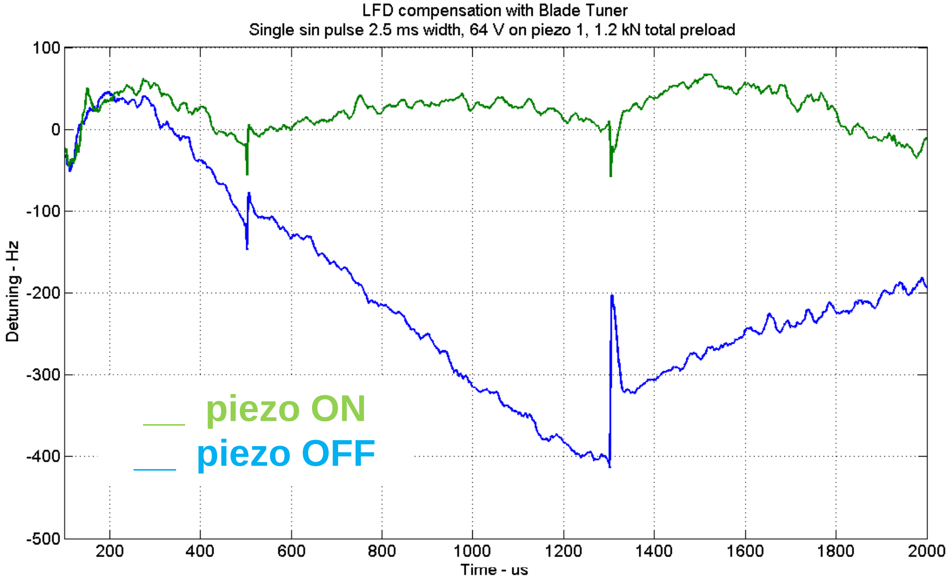
Tests were performed with different piezo preloads.

The correct value cancels the piezo unloading effect and enhances tuning sensitivity.

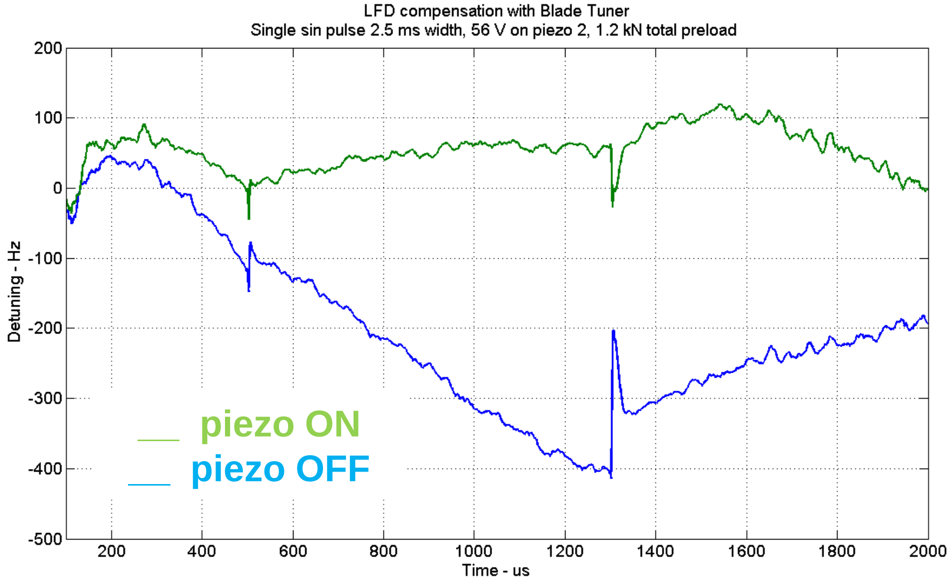
Tuning resolution met expectations, about **1.5 Hz/half-step** confirmed.

LFD compensation

- LFD exhibited by Z86 cavity, about 300 Hz, has been compensated:
  - Actuating each piezo alone (see plots)
  - Actuating both piezo in parallel



64 V on piezo #1



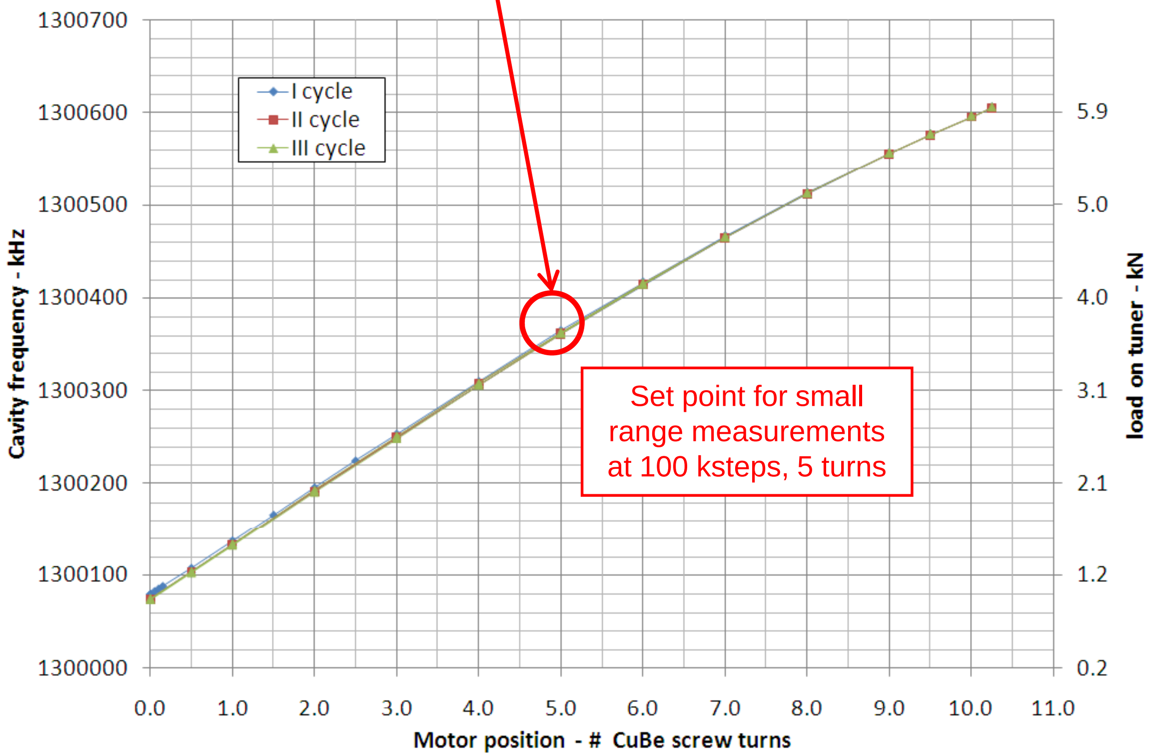
56 V on piezo #2

Nominal piezo pulse amplitude for this level of LFD is 60 V +/- 7%

Small tuning range analyses

Additional investigation of frequency tuning on a µm-scale:

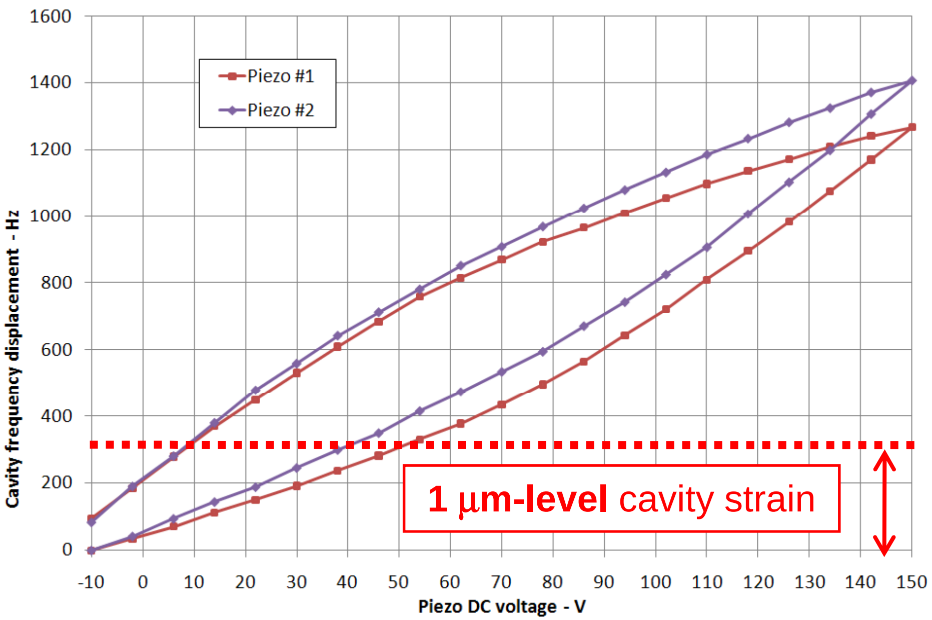
- Through piezo actuators static tuning range measurements. Piezo are driven with DC voltage.
- Trough drive unit small range measurements. Stepper motor is driven in a small range around a working point



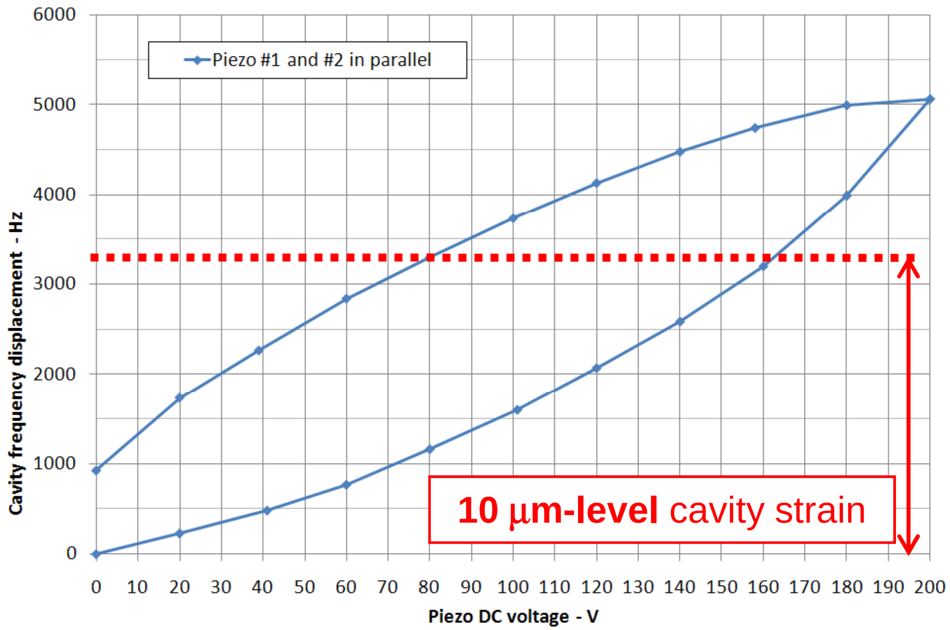
Piezo tuning range

- Each piezo actuator alone and also both in parallel have been driven with a DC voltage, the cavity frequency is locked by a PLL and measured.
- No deviation observed from the hysteresis curves expected from piezoelectric properties: no obstacles to the movement of piezo.
- Looking at plots a sub-micron resolution can be observed: 10 V step in piezo driving voltage corresponds to about 0.1 µm at low absolute voltage (where slope is lower)

Each piezo alone up to 150 V:
1.3 kHz +/- 10 % tuning range

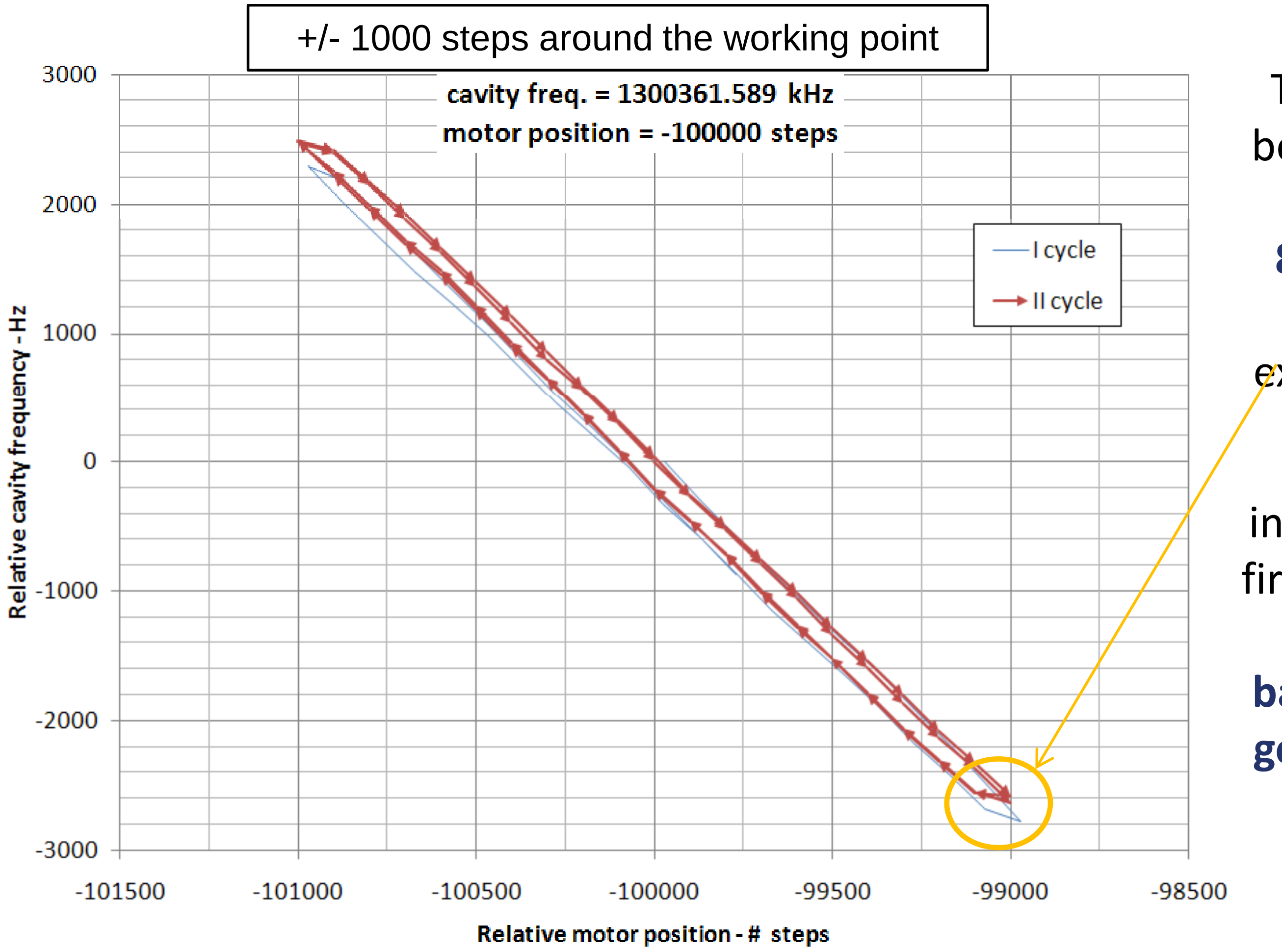


Both piezo together up to 200 V:
5 kHz tuning range



Drive unit tuning around the working point

tuning characteristics around a specific working point



The frequency positioning behavior and the amount of **backlash, about 85 steps**, is slightly higher than the one usually experienced with TTF tuner.

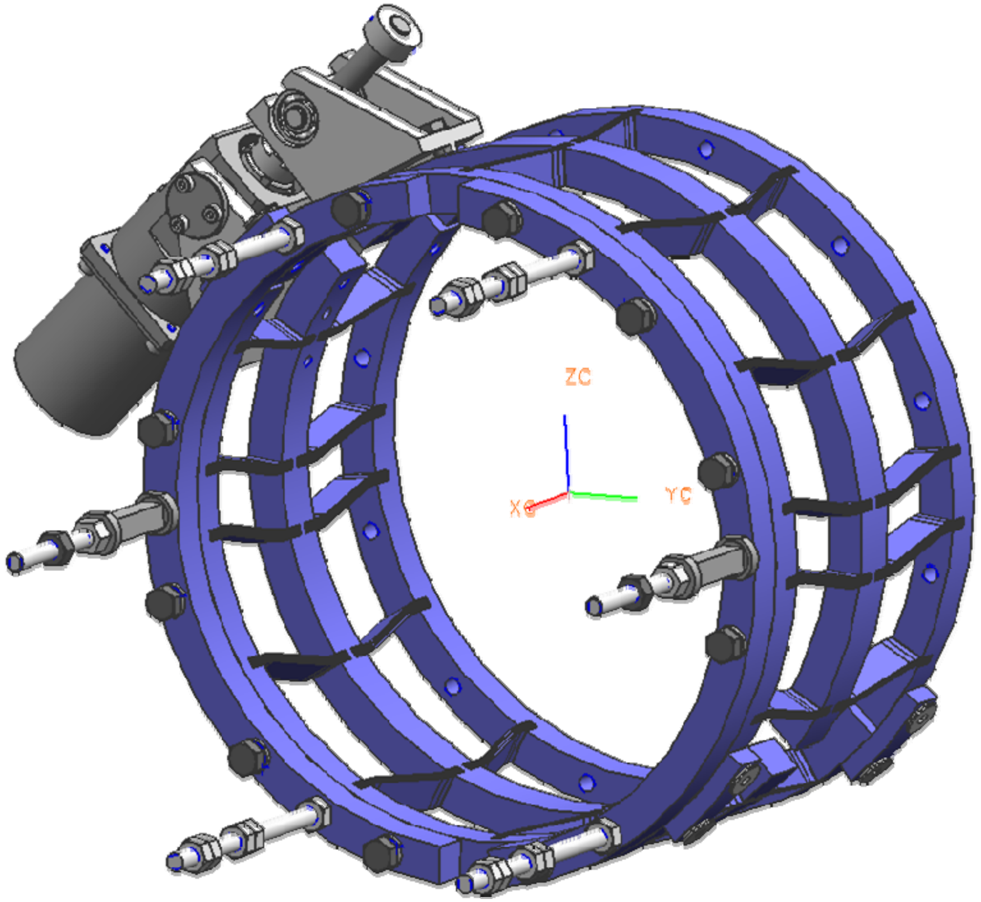
But the **planetary gear** installed, here tested for the first time, actually introduces a significantly **higher backlash if compared to HD gear, about 20 times higher**

The ILC Blade Tuner

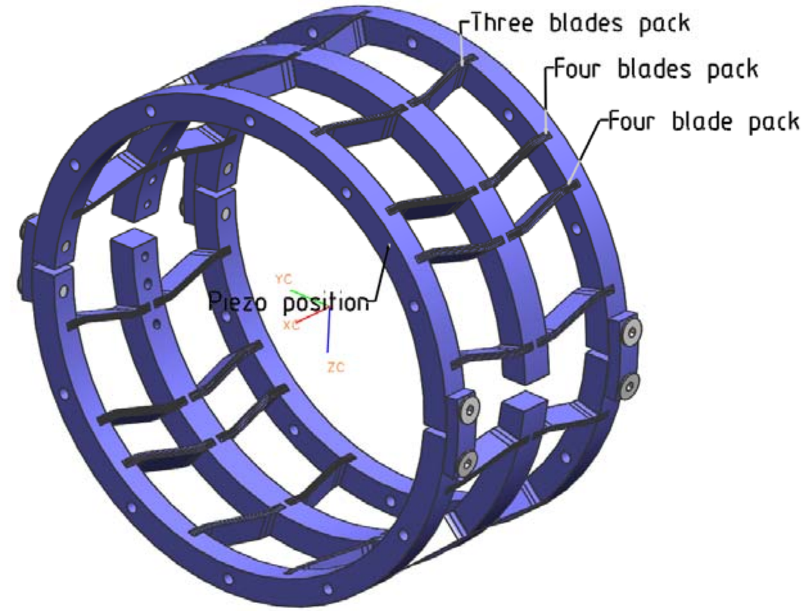
On the basis of the test results here presented the ILC Blade Tuner prototype is already designed to fulfill all the XFEL and ILC specifications.

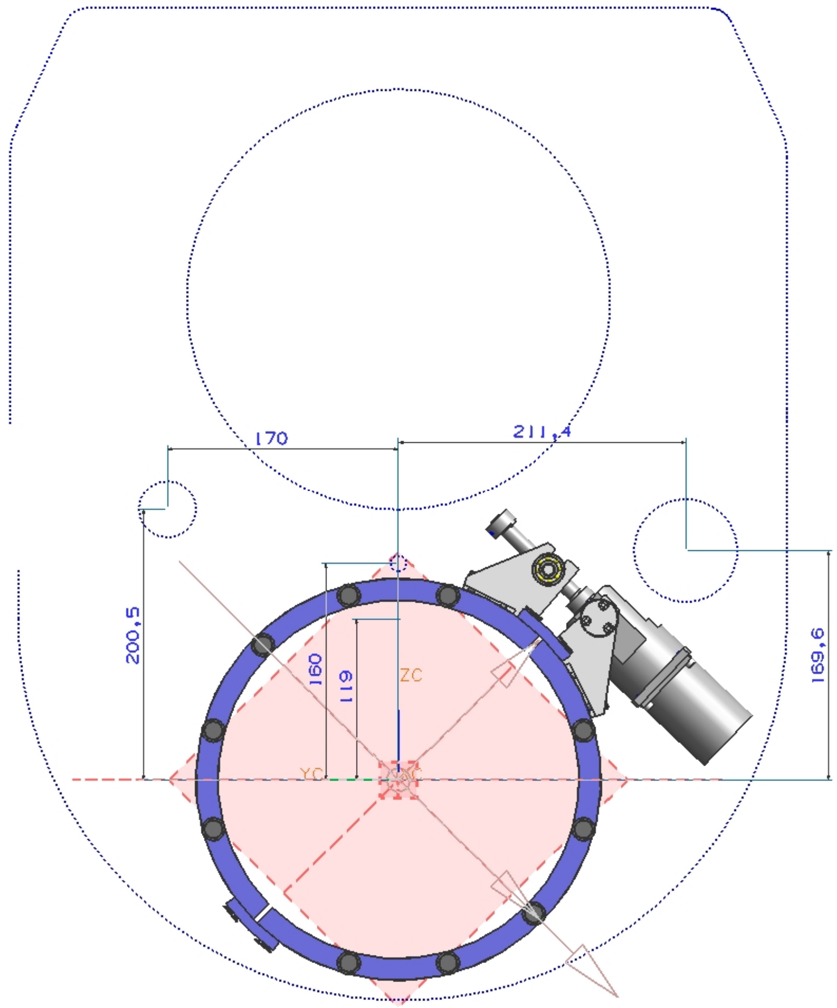
The experience gained with the cold tests on the so called “slim” prototype has been used for the final revision of the Blade Tuner design.

The first 8 units for Fermilab have been produced and more are under construction.



Geometry of the revised tuner 3.9.4



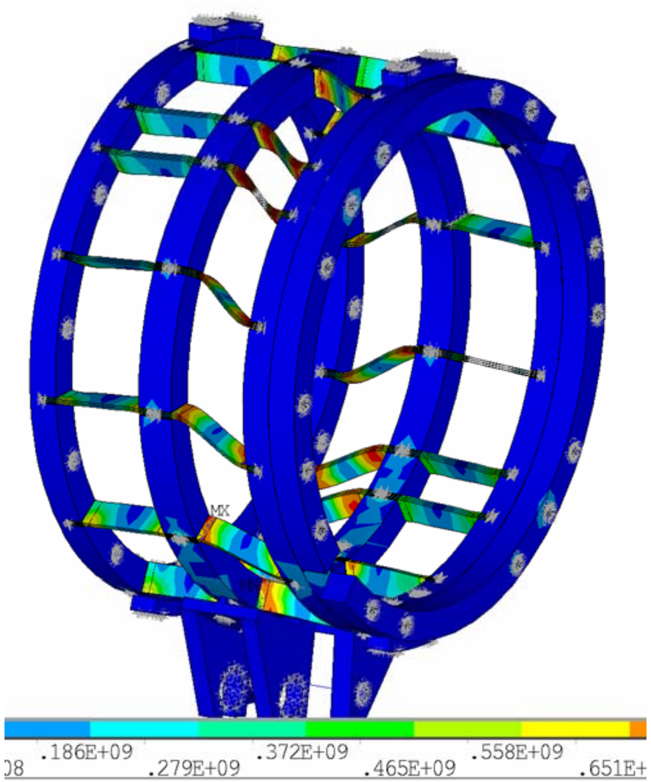


The piezo positions correspond to the double blade packs: as seen these packs withstand an higher load and therefore they were doubled.

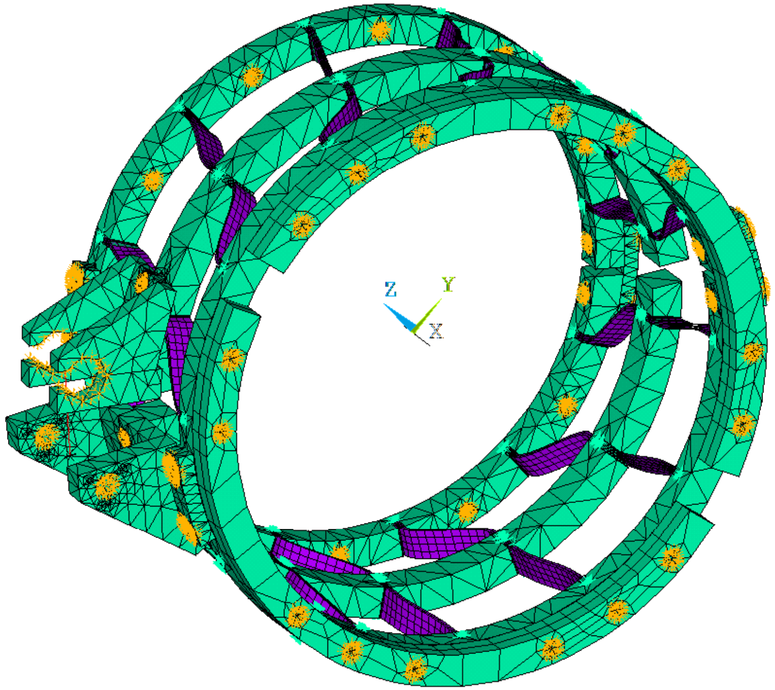
Design analysis – whole tuner

Possible failure modes for the revised Blade Tuner have been studied through a complete 3D FE model in order to evaluate its limit loads
In these analyses the tuner is at 0 screw turn position

Collapse at 11.6 kN



Buckling at 17.6 kN

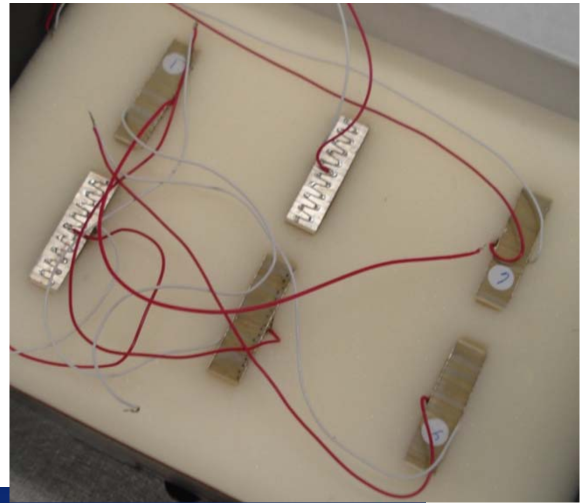


Revised Blade Tuner - conclusions

Tuner under construction	Tuner characteristics	Required value	Margin factor
Tuning range - nominal	0 – 600 kHz		
Max compression strength[2]	7800 + 3100 N	7800 + 1.1 * 2840 N (ASME)	1.0
Max traction strength	16000 N	13771 N (ASME)	1.16
Compression stiffness	15 – 100 kN/mm		
Mean freq. sensitivity	1.5 Hz/half-step - XFEL standard drive unit -	~ 0.75 Hz/half-step - actual TTF I tuner sensitivity -	
	0.75 Hz/half-step - devoted 1:200 gear -		
Max. torque at the CuBe screw	12.5 Nm - XFEL standard drive unit -	2.4 Nm	5.2
	25 Nm - devoted 1:200 gear -		10.4

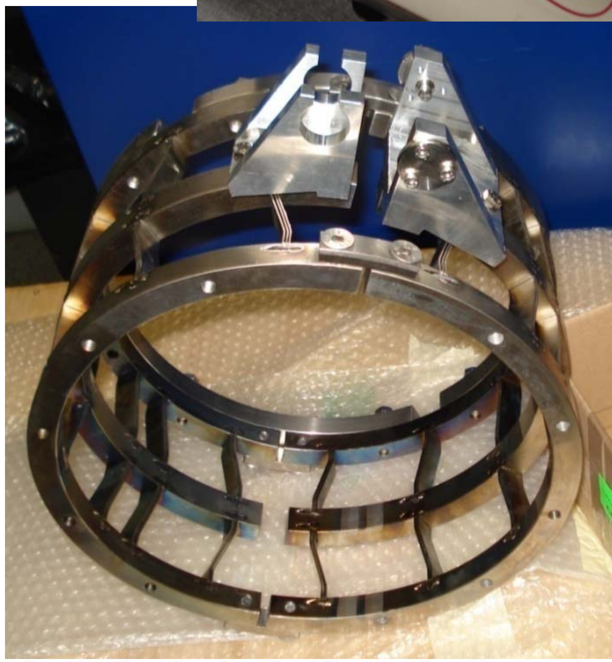
2 This is composed of the fixed part due to the cavity deformation and a variable part due to external pressure

Manufacturing



The first 8 units of revised Blade Tuner have been already manufactured.
Two more units are under production.

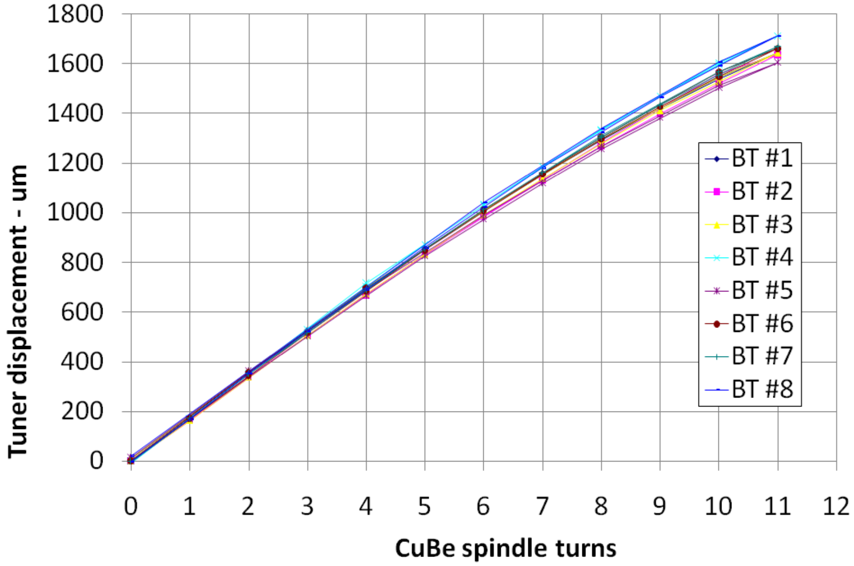
These revised Blade Tuners will fully equip the second cryomodule of ILC_NML test facility.

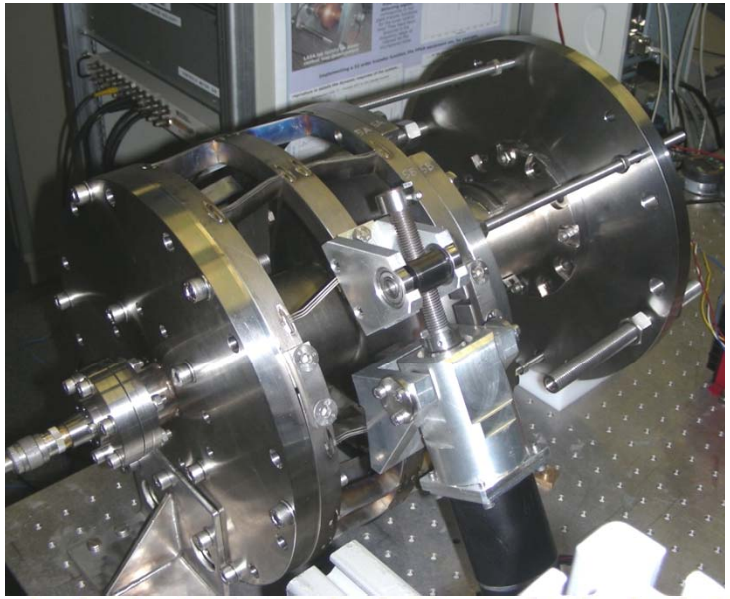


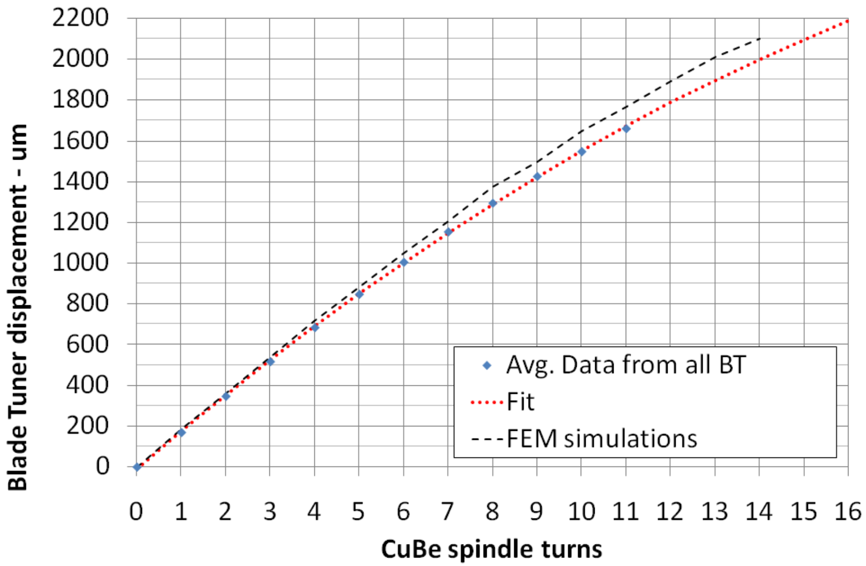
Room Temperature Qualification

The first 8 units produced in a small series have been tested for qualification at room temperature on a devoted single cell test facility

Results meet expectations in terms of **homogeneity** and **predictions** (in within 5 %)







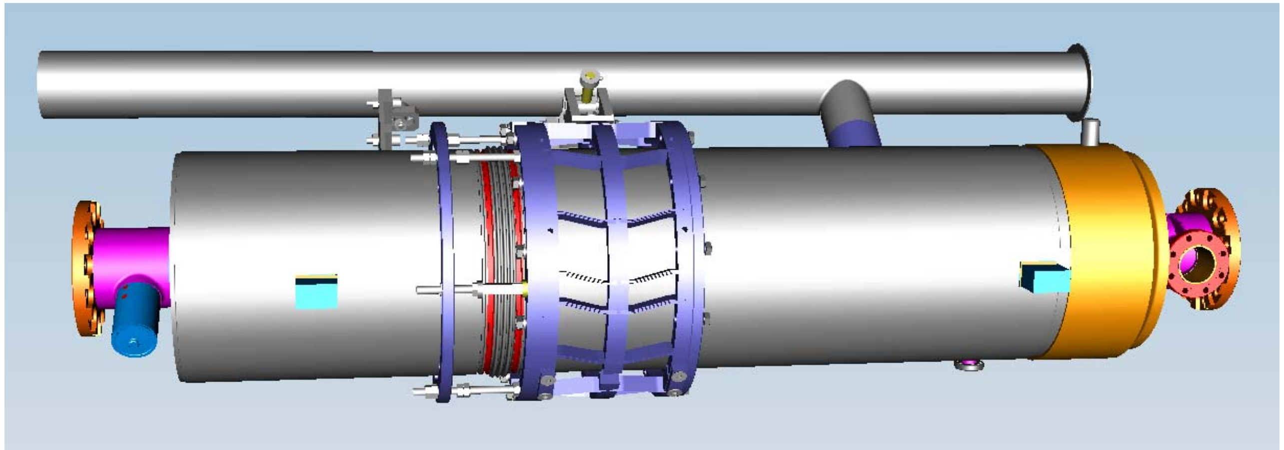
Revised Blade Tuner - conclusions

- Production and room temperature qualification of first 8 units of revised Blade Tuner satisfactorily completed.
  - 2 complete tuner system shipped to Fermilab. INFN group will now join FNAL team for installation and cold test of first units in horizontal cryostat.
  - Shipment of remaining 6 assemblies will shortly follow in view of the CM2 commissioning.
  - 4 additional Blade Tuner units have already been required by Fermilab. Production expected by this year.
  - 2 Revised Blade Tuner units will be also installed for the ILC S1-Global project in KEK, Japan.

- The revised Blade Tuner will be also involved in the existing collaboration with BESSY
  - Several research topics related CW and small BW application of SC cavities (ERL etc.): microphonics active compensation, ultra-small fast tuning range improvement (nm level)
  - Further horizontal cold tests planned from March 2009.
  - Special assemblies are currently under production in order to replicate Cry3+ pad sliding fixtures for incoming cold tests in HoBiCaT.

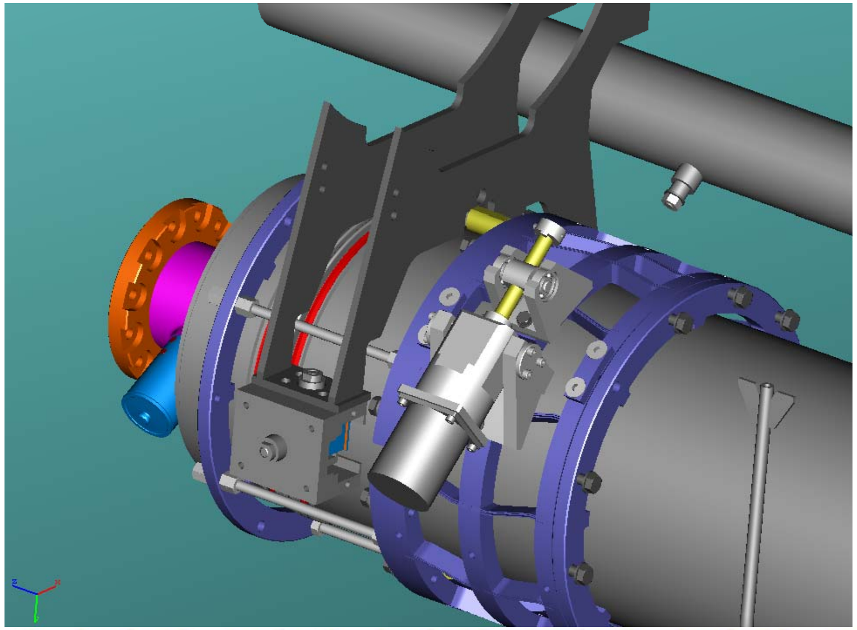
Tuner position considerations

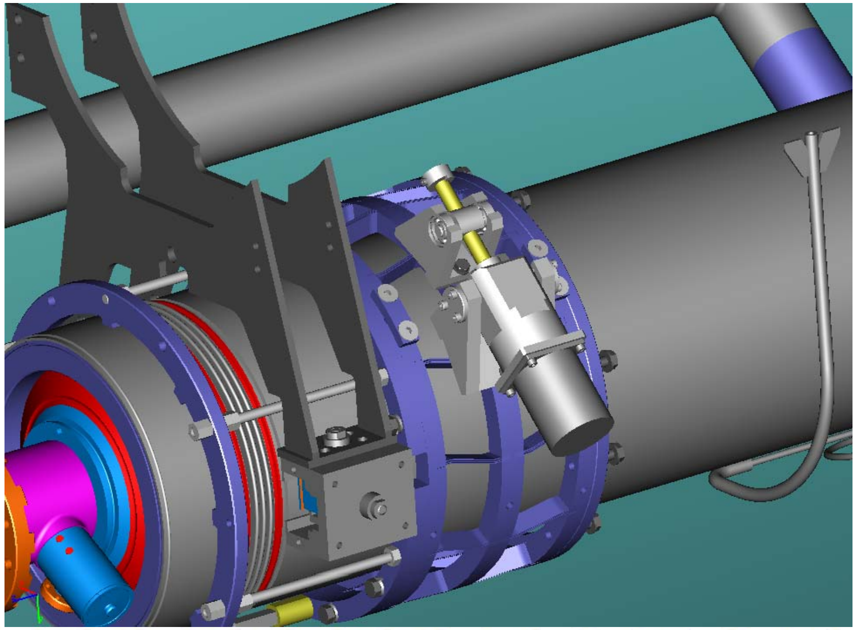
- The INFN proposed position is fine
  - Maintain the plug compatibility with FLASH-XFEL cavities
  - Produce a negligible static deformation of 0.13 mm. Moving the bellow at the tuner center the sag increases to 0.16 mm.
  - No backlash on the rollers:
    - Superstructures data
    - Analyses of data collected with prototype cold tests
    - Further experimental data from incoming cold tests at BESSY
  - Easy and proven assembly procedure



Alternative positions evaluated

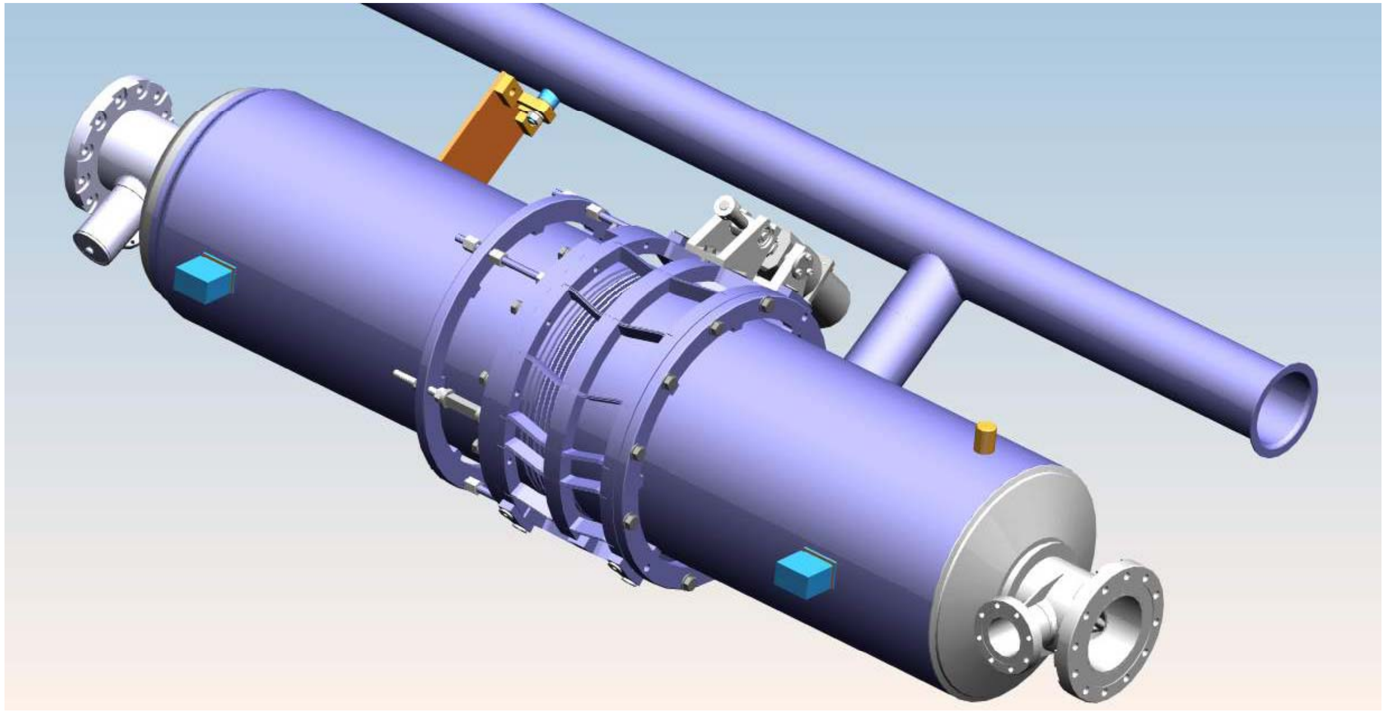
- Anyway, proofs are better than doubts, so:
  - Basic preliminary studies have been done to evaluate the possibility
  - The Blade Tuner is fully compatible. No modifications are required to the tuner assembly.
  - The solution would require a double set of holes in one of the two flanges welded on the helium tank
  - Some major problems: bellow welding, shield design and assembly





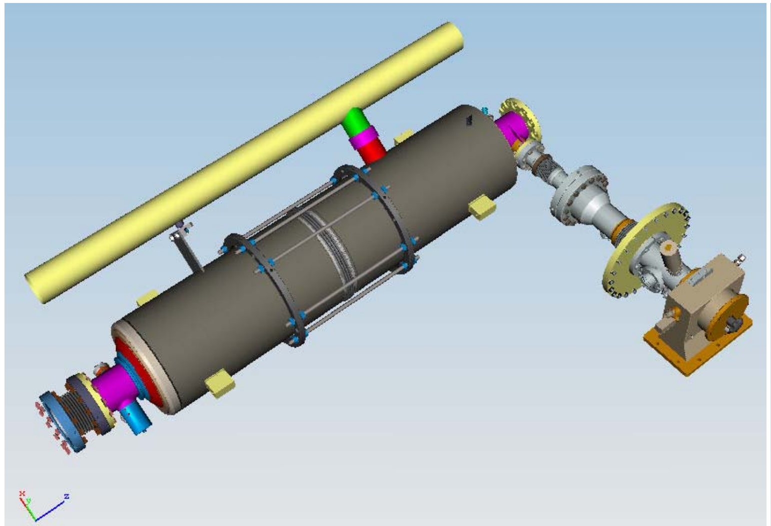
ILC-XFEL Plug Compatible Cavity

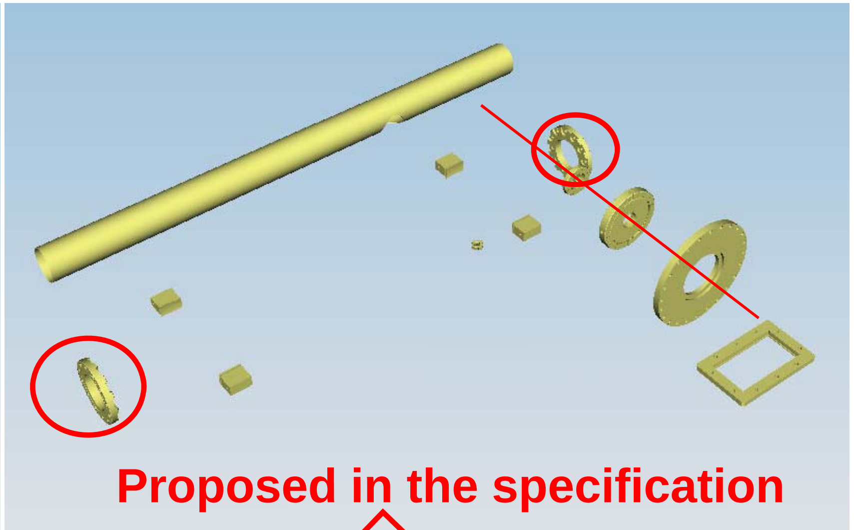
- Cavity with Helium Tank, Tuner and pipe connections
  - Plug Compatible with the 3 Regional Infrastructures
  - Plug Compatible with the FLASH and XFEL Cryomodules



INFN Milan strongly promotes and supports the plug compatibility concept to make the best use of XFEL expected synergies for the ILC

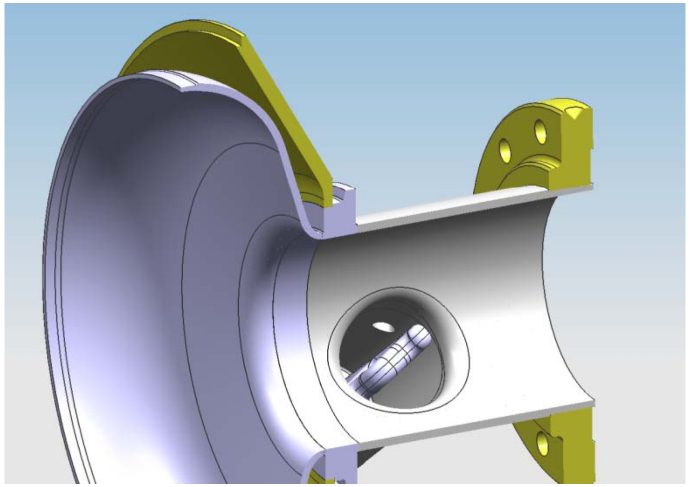
Plug Compatibility Concept





Helium Vessel Body		KEK-STF-BL	KEK-STF-LL	FNAL-T4CM	DESY-XFEL
Helium Jacket	Material	Ti	SUS	Ti	Ti
	Slot length, mm	1337	1337	1326.7	(1382:Type3)
	Distance between beam pipe flanges, m	1258.6	1254.5	1247.4	1283.4
	Distance between bellows flanges, mm	78.4	85,2	80.49 (cold)	
	Outer diameter, mm	242	236	240	240
Beam Pipe Flange	Material	NbTi	Ti	NbTi	NbTi
	Outer diameter, mm	130	140	140	140
	Inner diameter, mm	84	80	82.8	82.8
	Thickness, mm	14	17.5	17.5	17.5
	PCD, bolts	ϕ115, 16-ϕ9	ϕ120, 16-ϕ9	12, M8 SS studs	12, M8 SS studs
	Sealing	Helicoflex	M-O seal	Al Hex Seals	Hexagonal Al ring
	Distances between the connection				
	surface and input coupler axis	62, -1196.6	58.1, -1213.9	60.6, -1186.8	60.6, -1222.8

EU funded study for new end groups

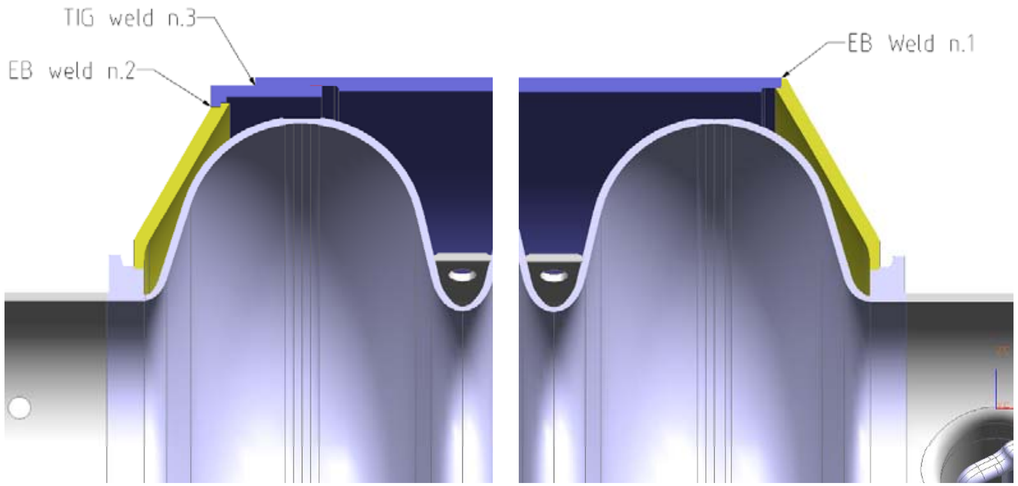


Motivation

- Decrease cost of end-group parts.
- Reduced number of welds and simplified sequence.
- Same axial stiffness than actual solution
- Compatible with XFEL tools
- Optimized for the coaxial tuner

2 end group prototypes successfully produced and ready for mechanical test

One 9-cell cavity prototype hopefully coming soon



Present ILC Activities at LASA

- Participation to GDE organized Meetings with people and expertise (Main linac, SCRF, Cryogenics, Vacuum)
- Promotion and support of the plug compatibility concept to make the best use of XFEL expected synergies for the ILC
- Pursue the very promising R&D work on cavity HPR and optical diagnostic, while in the stringent resource limitations
- Consolidate the Blade-Tuner system design with extensive tests at BESSY and Fermilab
- Realization and test of the 2nd, Type 3, Cryomodule for Fermilab
- Qualification and test of the 8 Blade-Tuners for the 2nd Fermilab cryomodule
- Realization and test of the S1 Global Cryomodule for KEK
- Pre-series production of the tuning systems for 24-30 high gradient cavity packages, in the frame of ILC-HiGrade.

Toward first Financial Report

Several issues were involved and results achieved since the beginning of the activity, to be included in the **ILC HiGrade Year 1 Financial Report** currently under finalization:

- INFN personnel
- Internal travelling, mainly as collaboration activity with Italian manufacturer on place.
- External travelling, participation to meetings and testing of tuner prototypes.
- Realization of Blade Tuner prototypes
- Purchasing of Blade Tuner assembly key components (piezo actuators, stepper motors and control electronics)
- Realization of a coaxial tuner test assembly for room temperature qualification

Tentatively: 50 to 70 k€

Conclusions

- The SCRF Group at INFN Milano - LASA is strongly motivated on the ILC
- The INFN LASA expertise remains fully available for the ILC
- All possible synergies between LASA funded research activities and the ILC are promoted and pursued
- The effective contribution is mainly limited by the available resources: funds and personnel