Cavity Tuner Development for the ITN Cryomodule at KEK

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on the behalf of the ITN tuner team

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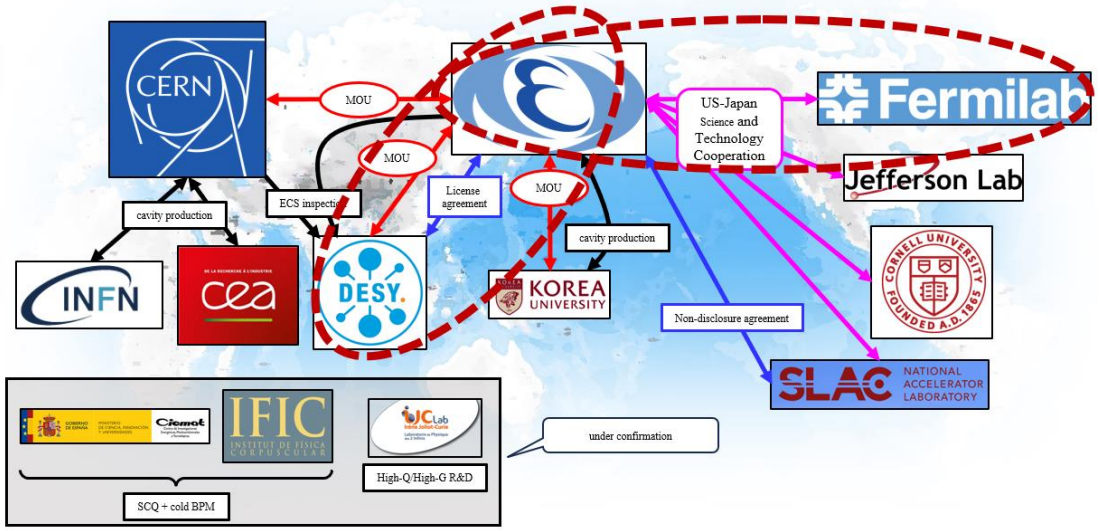
Introduction

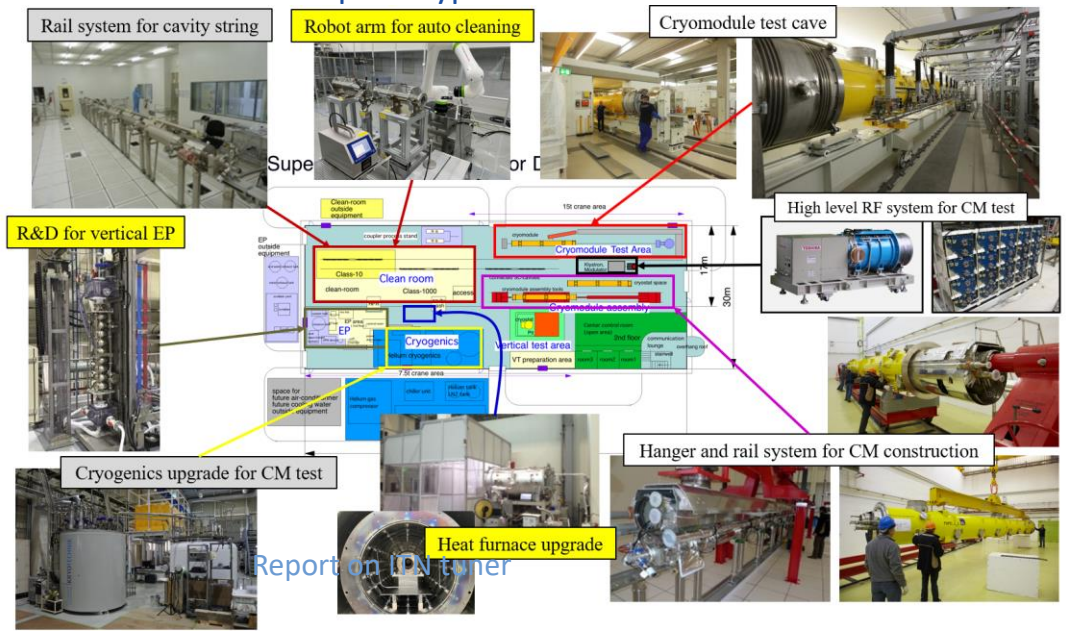
- ILC Technology Network (ITN)
  - The ILC International Development Team (IDT) was established by the International Committee for Future Accelerators (ICFA) to pave a way towards the preparatory phase of the ILC.
  - The ILC Technology Network is initiated, jointly by the High Energy Accelerator Research Organization (KEK) and IDT to execute high priority work packages for the ILC Pre-lab proposal.
  - ITN is an independent organization based on arrangements between KEK and participating laboratories.
- From 2023 to 2027 we will build and test an ILC prototype cryomodule at KEK, including all necessary infrastructure

For more details see talk from T. Saeki, "Status of fabrication of 9-cell cavities"

Global collaboration on SRF for MEXT-ATD/ITN



ILC prototype CM and its infrastructure



Timeline for ITN tuner

Activities	FY2023	FY2024	FY2025	FY2026	FY2027
Selection of tuner, preparational work					
Production and test of prototype tuner					
Series production					
Component testing, pre-assembly					
CM assembly, CM test					

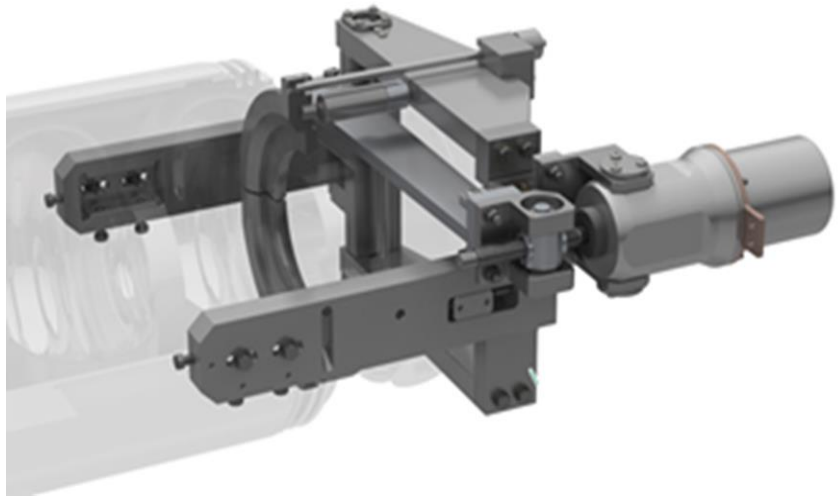
Tuner selection

- Requirements
  - Maximal force on the cavity 8.4 kN
  - 2 mm displacement (operational)
  - Lorentz Force Detuning compensation for gradients up to 40 MV/m (~2 kHz)
  - Reliable
  - Low cost
  - Compact (short beam pipe)
  - Derive from proven design

→The ITN tuner will be based on LCLS-II tuner
  - Only solution for short beam pipe

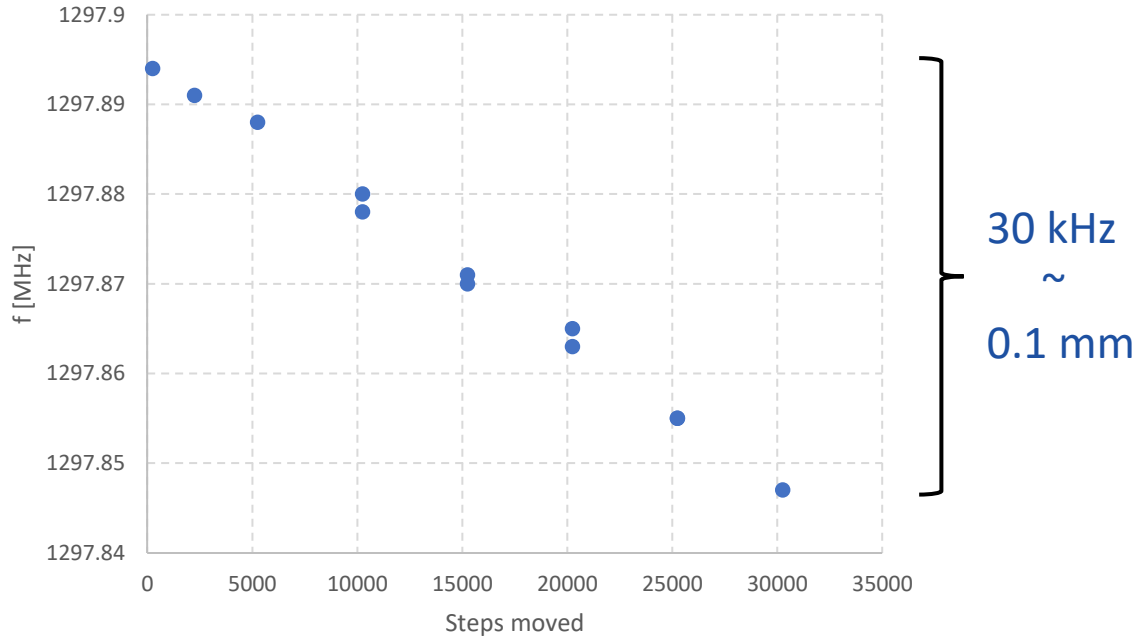
ILC TDR: Table 3.8 Main specifications of the frequency tuner.

Tuner	Parameter	Specifications
Slow tuner		
	Tuning range	> 600 kHz
	Hysteresis	$< 10\,\mu$m
	Motor characteristics	Step motor, power-off holding, magnetically shielded
	Motor location	Inside 5K shield, accessible from outside
	Magnetic shield	$<$ 20mG
	Heat load by motor	< 50 mW at 2 K
	Motor lifetime	$> 20 \times 10^6$ steps
Fast tuner		
	Tuning range	>1KHz at 2 K
	LFD residuals	$<$ 50 Hz at 31.5 MV/m flat-top
	Actuator	Piezo actuator, located inside 5K shield, Two actuators for redundancy
	Heat load by actuator	$<$ 50 mW at 2 K
	Magnetic shield	$<$ 20mG
	Actuator lifetime	$> 10^{10}$ pulses



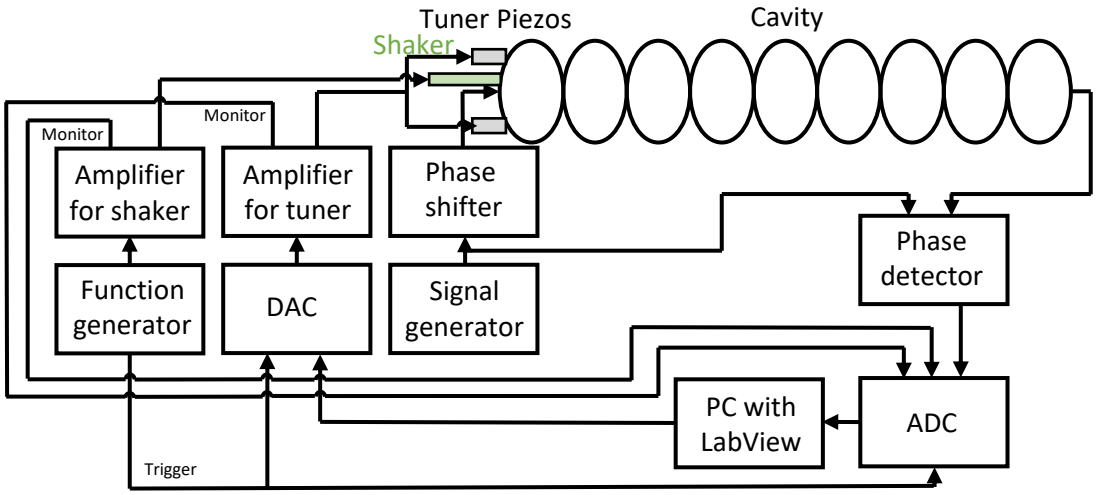
Collaboration with Fermilab under the US-Japan Collaboration Program in HEP

- KEK lend from Fermilab an LCLS-II cavity and LCLS-II tuner
- Joint setup and test at KEK
  - Slow tuner test (not full range)

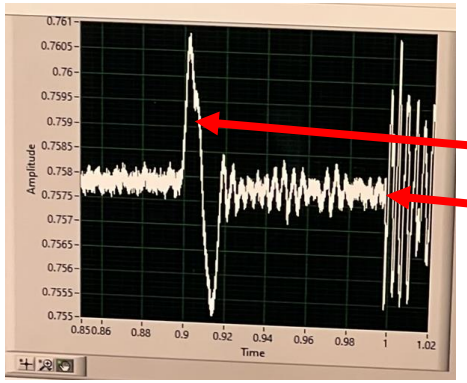


Collaboration with Fermilab under the US-Japan Collaboration Program in HEP

- Cavity at room temperature and atmospheric pressure
- Simulated LFD compensation
- Successfully demonstrated 1 Hz operation



Phase detector output voltage vs time:

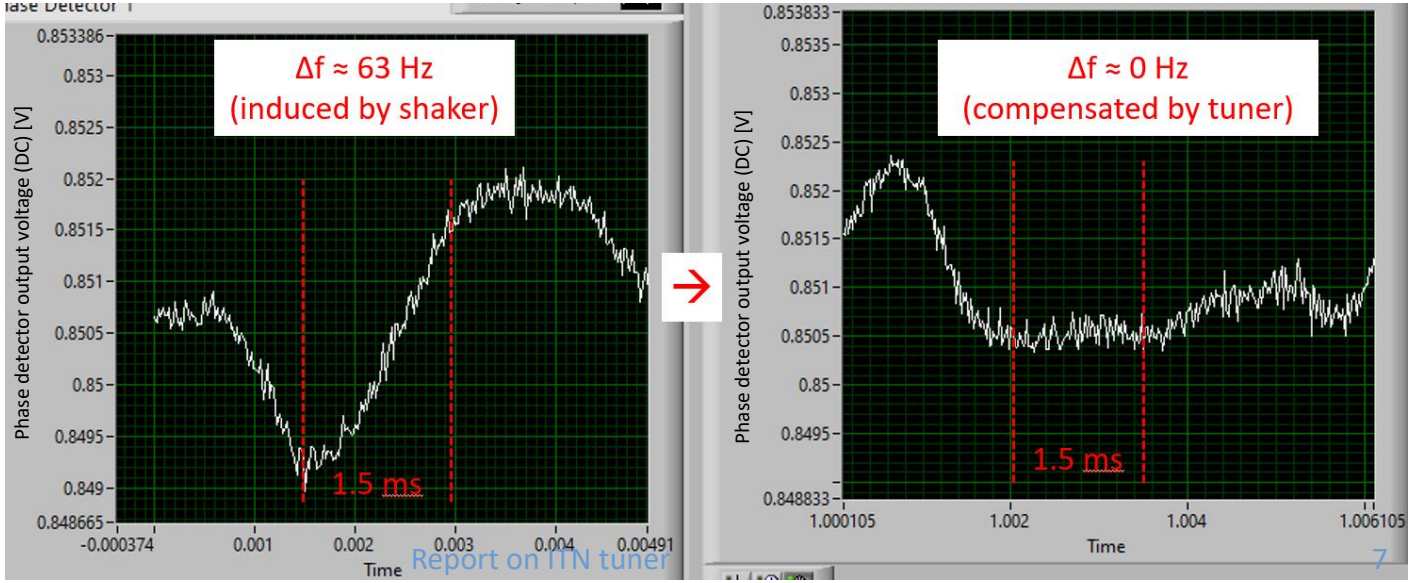


Example drive with 1 Hz repetition rate:

- Piezo 50 Hz sine (LabView/DAC)
- Shaker pulse (2 ms) (function generator)

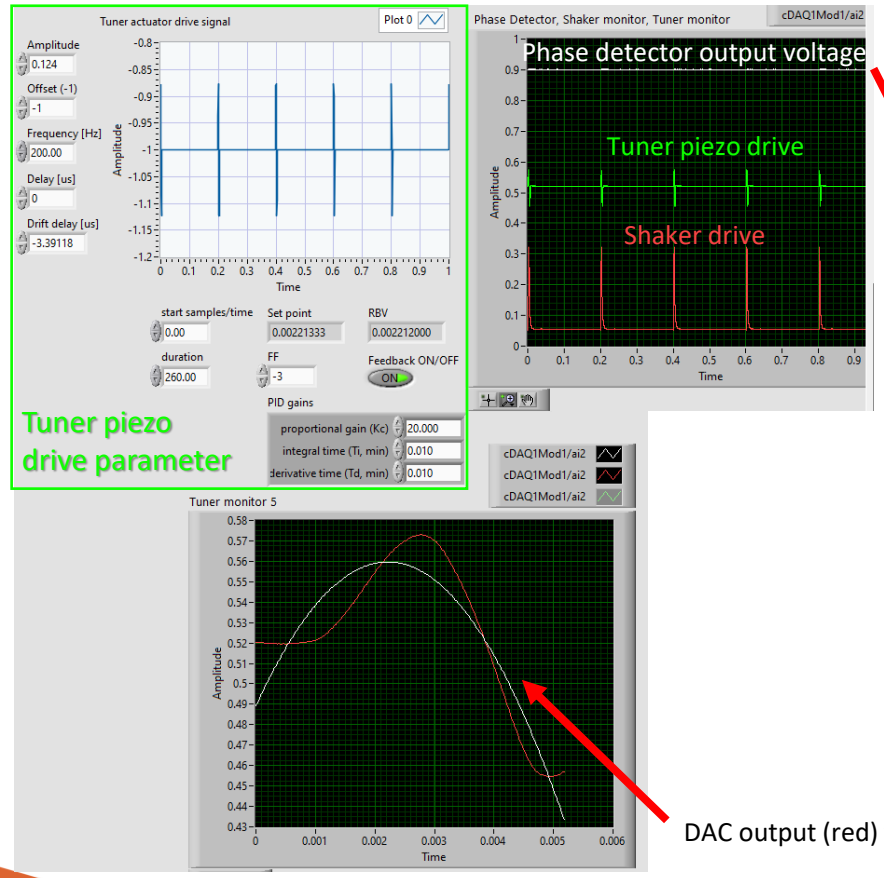
1) only shaker

2) shaker plus tuner piezos



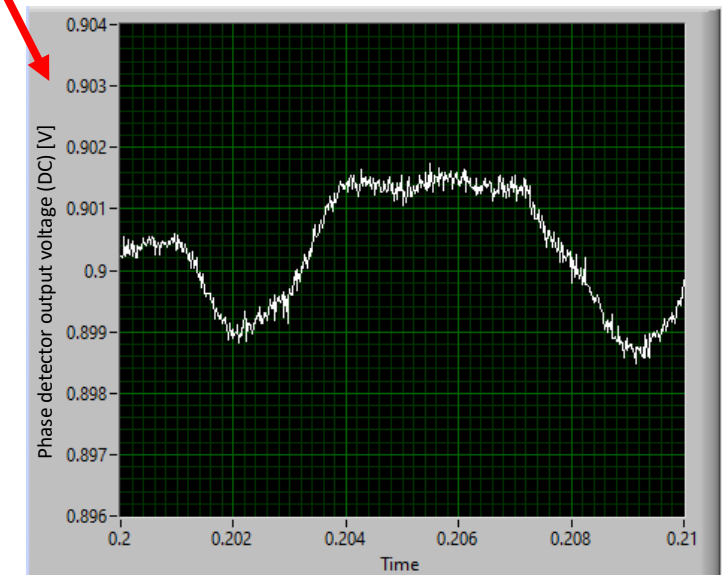
Further development at KEK for 5 Hz operation

- To demonstrate CM-like operation at 5 Hz repetition rate
- Wrote new LabView code to allow stable 5 Hz operation
- Suppressed DAC drift with PID controller

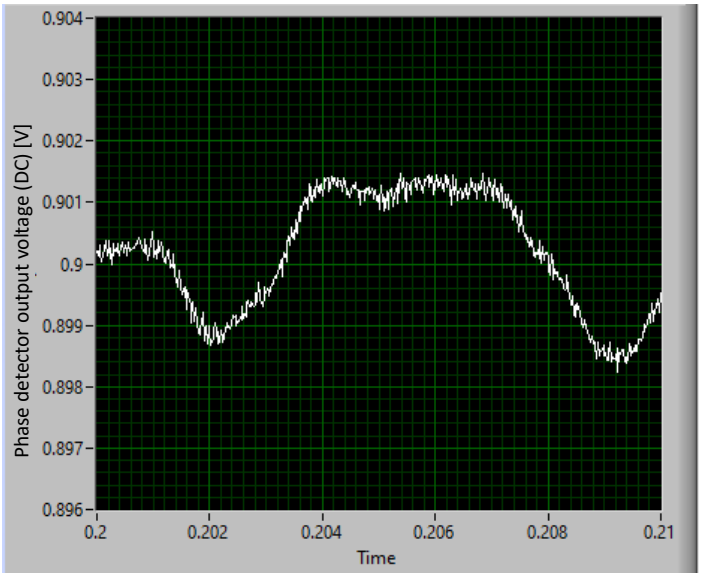


DAC output (red) with fit (white) for drift compensation

Phase detector output voltage vs time

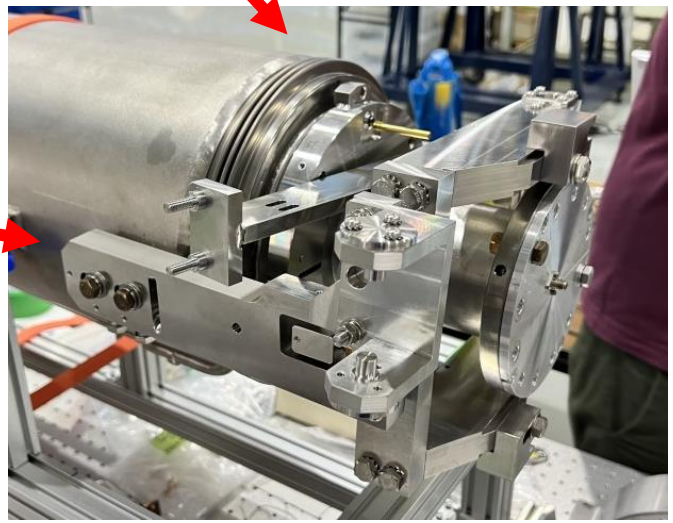


126 min. later



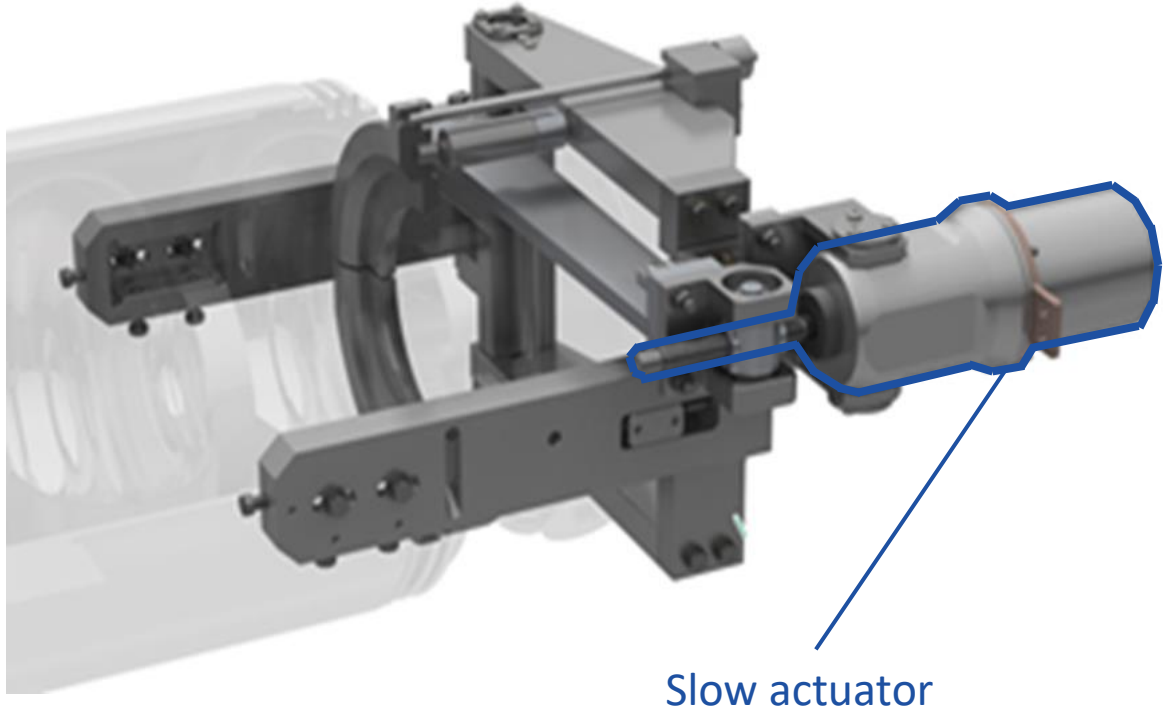
First domestically produced ITN tuner prototype

- Difference to LCLS-II tuner
  - All metric
  - Stainless steel screws
  - Bearings only for room temperature test
- Pre-assembly and assembly on LCLS-II cavity went smoothly



Status of slow actuator (stepper motor & gear)

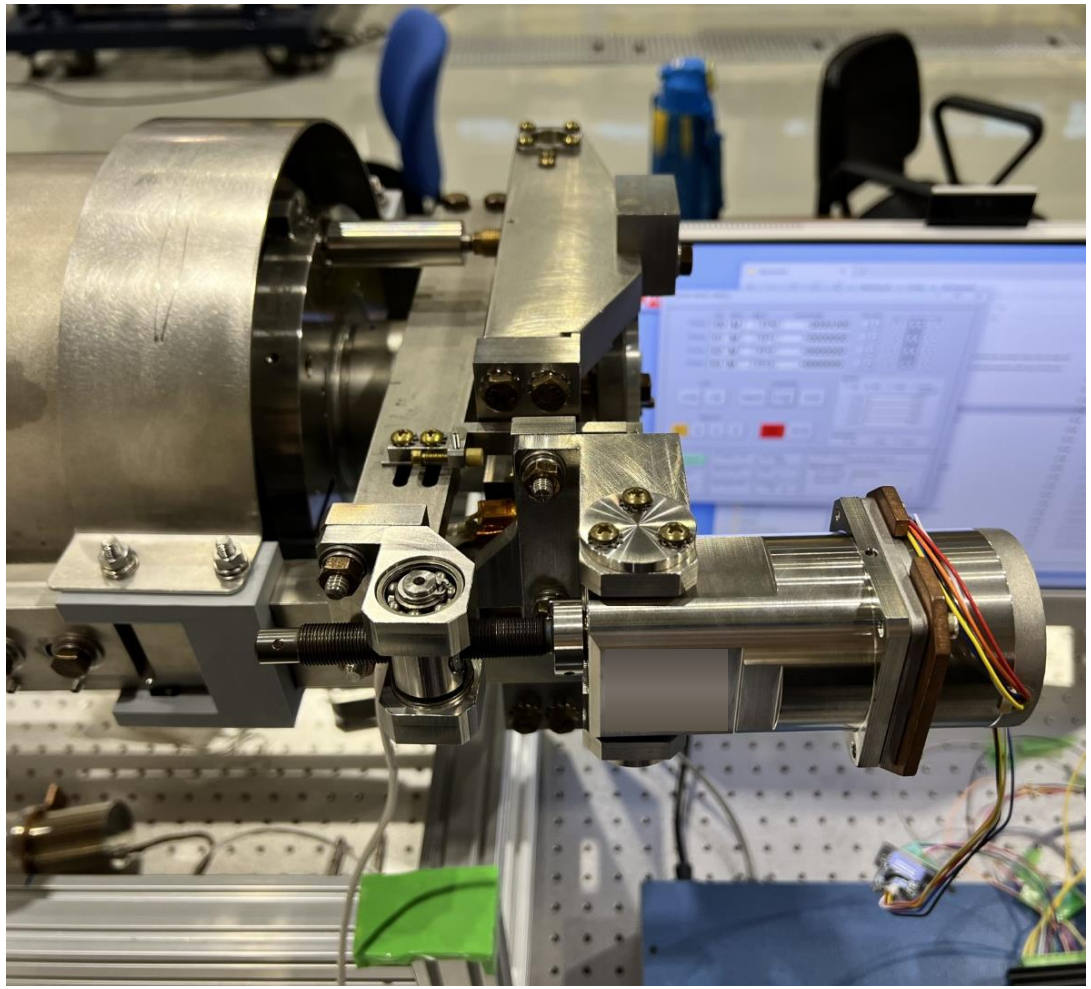
- LCLS-II tuner uses stepper motor A
  - Specifications exceed our need drastically
  - Discrepancy between budget and quoted cost
- Basically, no alternatives available on the market
  - Motor must operate at cyrogenic temperatures (~20 K)
  - And in vacuum (10^{-5} Pa ~ 10^{-6} Pa)
- European XFEL tuner uses stepper motor B
  - Received one unit from DESY for testing purposes
  - Product reached already end of life
  - Started discussion with company towards a new product

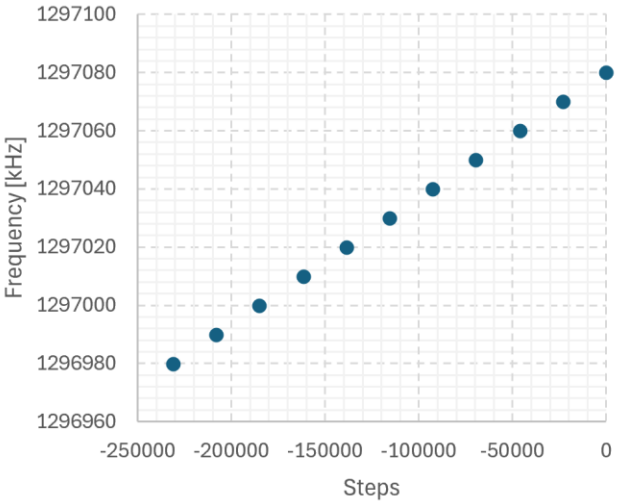


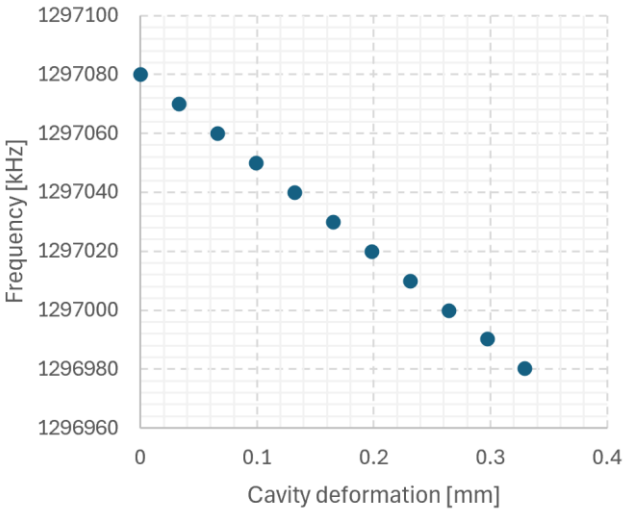
LCLS-II tuner (with motor B)

- Usage of piezo dummies
- Cavity pre-loaded by 50 kHz
- Tuned cavity by 100 kHz by slow tuner

→ Also motor B works with the LCLS-II tuner





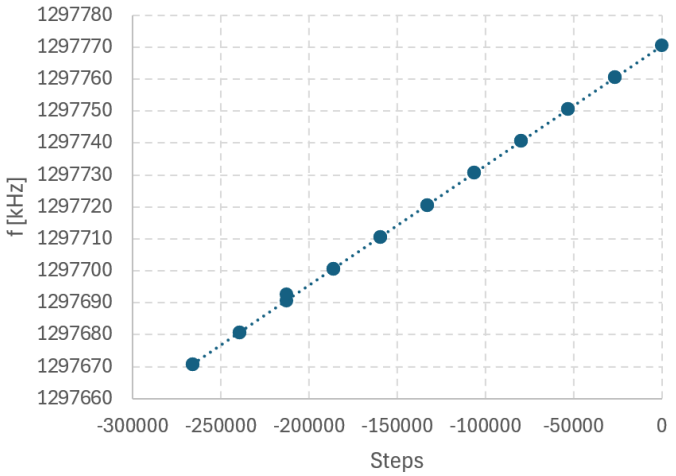


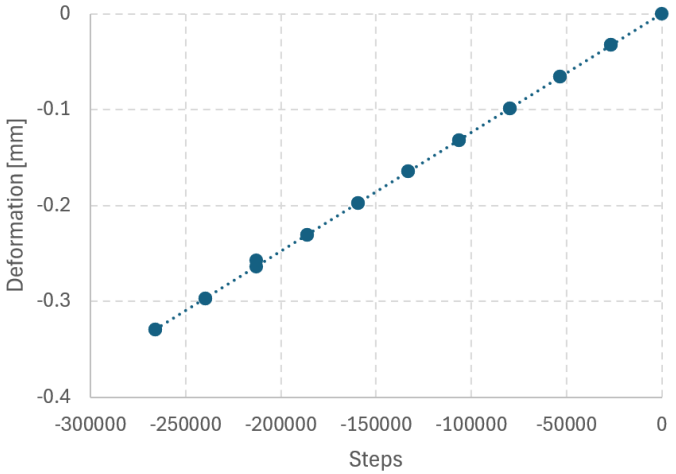
First time tuning of an LCLS-II cavity with a domestically produced ITN tuner while using motor B

- Usage of piezo dummies
- Cavity pre-loaded by 50 kHz
- Tuned cavity by 100 kHz by slow tuner

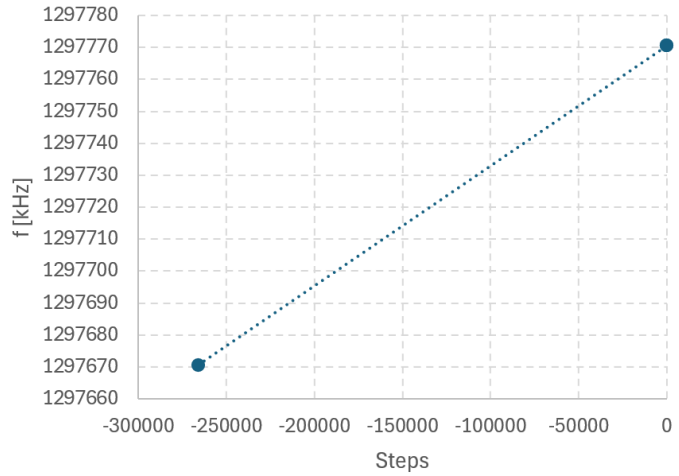
→ Motor B also works with ITN tuner

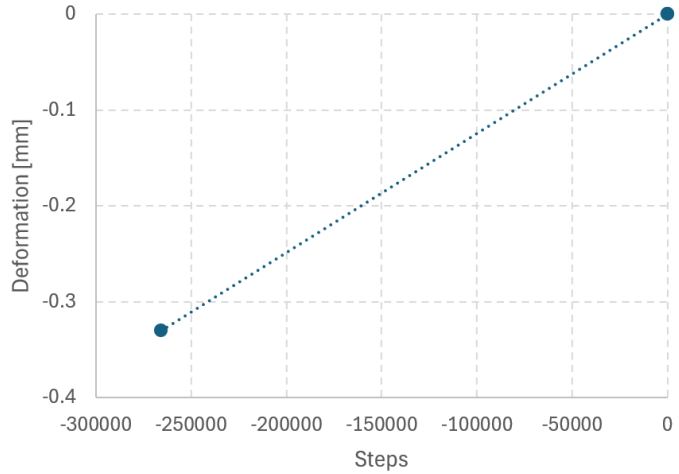
Scan of steps (back and forth)





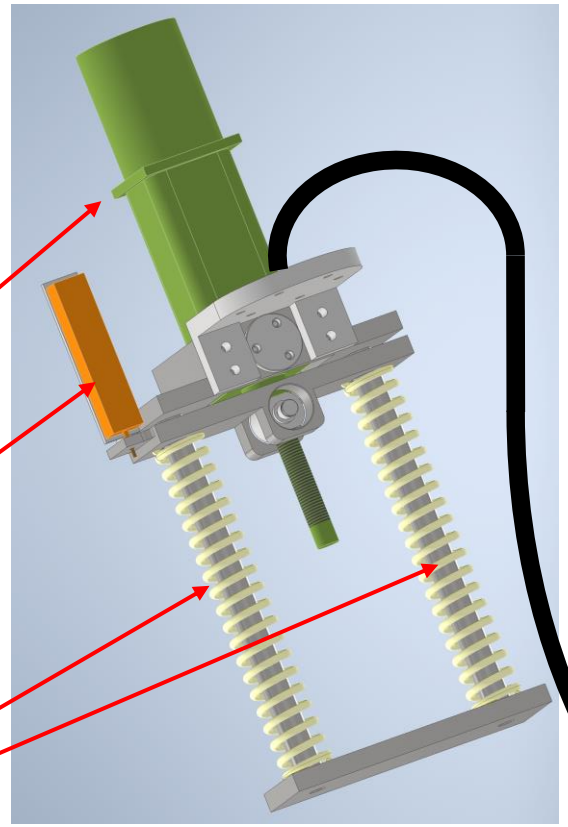
Full way in one go (back and forth)

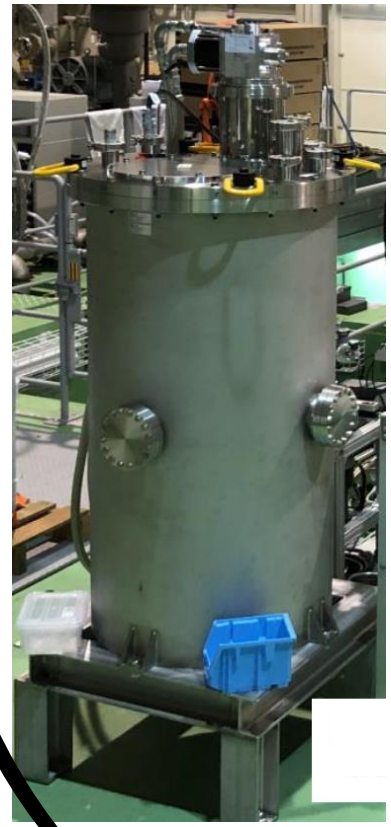


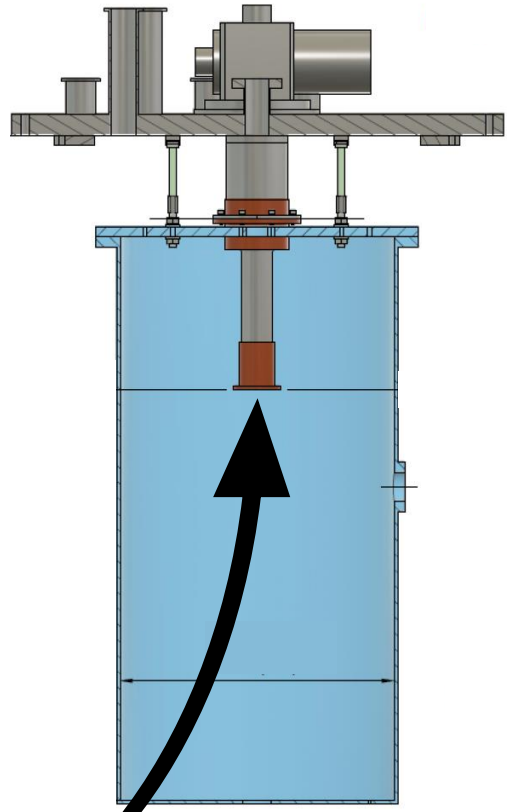


Plans for stepper motor/gear cold test setup

- Slow actuator test
  - Before CM assembly
  - Within cryo-cooler cryostat
    - Operation at cyrogenic temperatures (~20 K)
    - Operation in vacuum (~10^{-6} Pa)
  - Motor with gear
  - Potentiometer to measure displacement
  - Two springs simulate cavity and tuner

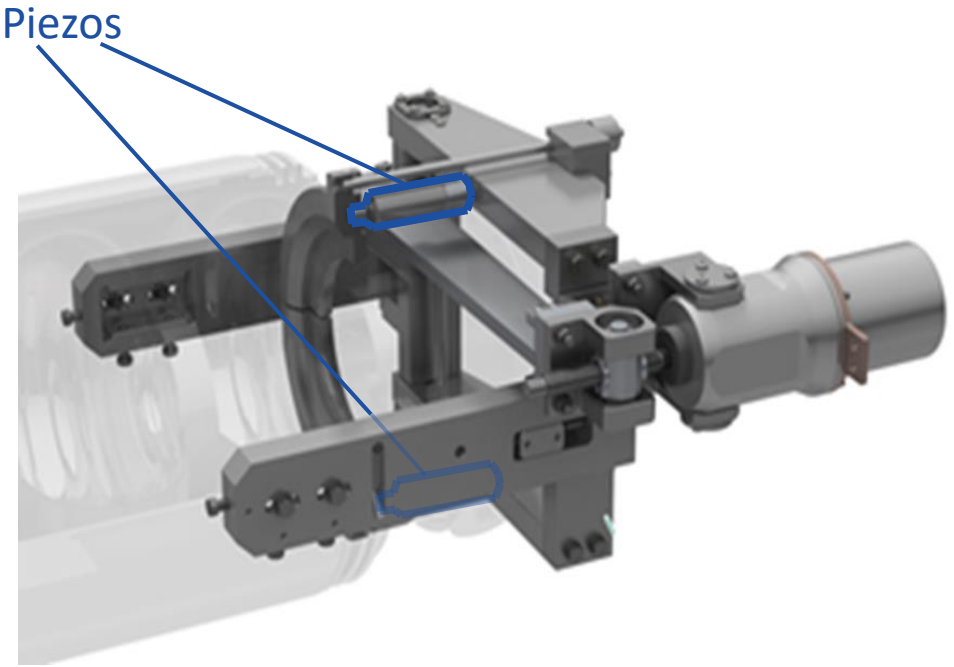






Status of fast actuator (piezos)

- Fermilab develop a special piezo setup
  - Encapsulation with non-magnetic metal
  - Ball joints between piezos and tuner and cavity (split ring), respectively
  - Etc.
- Product still available
  - Discrepancy between budget and quoted cost
- Need to find a solution to reduce cost
  - E.g. simpler piezo design



"Frequency stability of the SRF cavities (microphonics)", Y. Pischalnikov

Outlook

- Tuner body
  - Production of second-generation prototype
    - Slight changes on side plates to allow easier assembly
  - Test at room temperature
  - Finalize design for series production
  - Series production
- Slow tuner
  - Production of slow actuator cold test stand
  - Production and test (at room temperature and in cryostat) of prototype slow actuator
  - Series production
- Fast tuner
  - Find a suitable piezo
  - Production and test (at room temperature and in cryostat) of prototype fast actuator
  - Series production

→ Operation within ITN CM

Summary

- ILC prototype CM under construction at KEK, test end of FY2027
- ITN tuner is a derivate of the LCLS-II tuner
- First domestic prototype was produced and successfully tested at room temperature
- Finding suitable actuators is challenging
  - Solution for slow tuner potentially found
  - Strategies for finding solutions for fast tuner prepared
- Preparations for component tests in cryostat have begun

Thank you very much for your attention! Questions?

- **KEK ITN tuner team**
  - Mathieu Omet
  - Kensei Umemori
  - Yasuchika Yamamoto
  - Takeshi Dohmae
  - Ashish Kumar
  - Tomohiro Yamada
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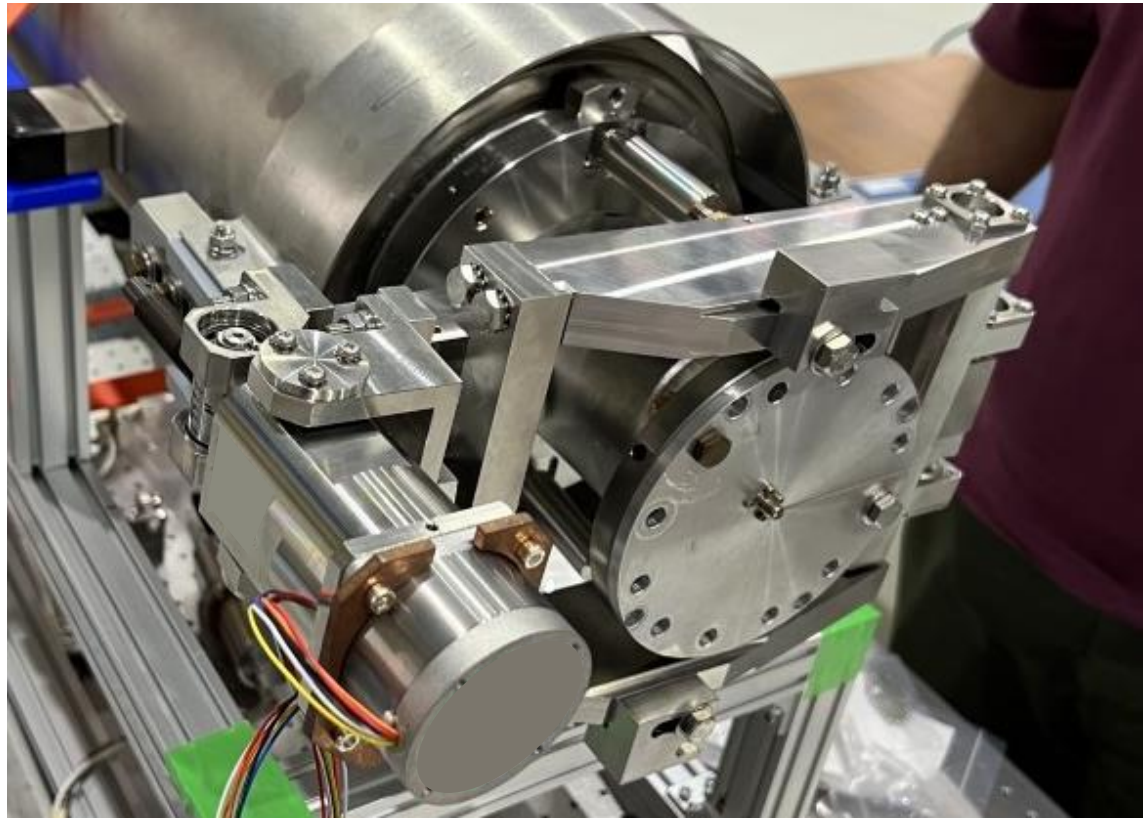
  - Sergey Belomestnykh
  - Yuriy Pischalnikov
  - Crispin Contreras-Martinez
- **Acknoledgements**
  - Hans Weise (DESY)



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