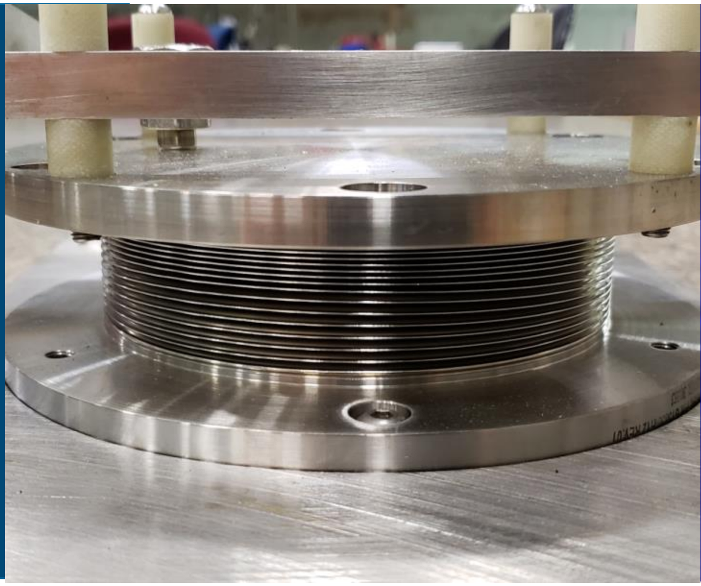
Low Beta Tuner Design (ANL Pneumatic Tuner)



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Second Topical Workshop on Cryomodule Microphonics and Resonance Control

October 25-26, 2018

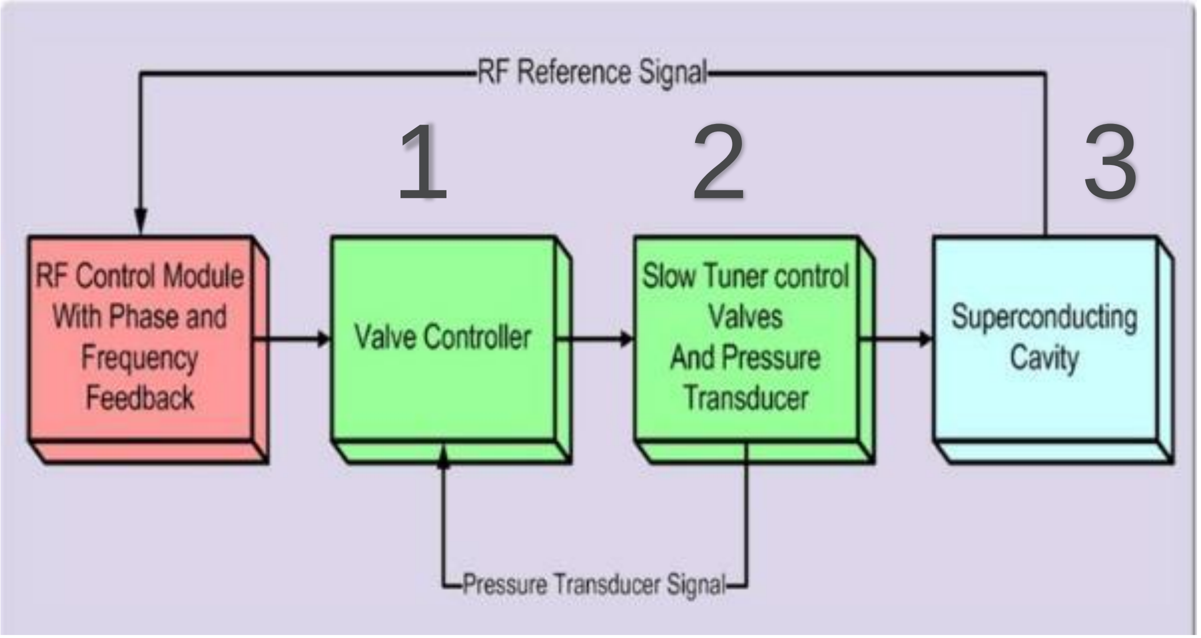
Opening Remarks: ANL Pneumatic Tuner for Superconducting Cavities

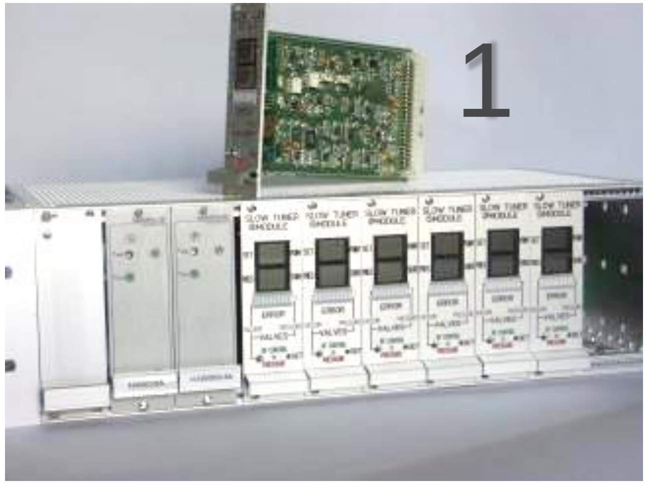
- **Purpose:** Tune cavity frequency to within ~1 Hz of a master clock in the presence of detuning forces (helium pressure, CW Lorentz detuning)
- **Concept:** Use helium pressure inside an expandable bellows to tune each cavity's frequency
- **History**: 4 decades in ATLAS; >5x10^6 operating hours with 77.82 hours of downtime from 1994 to 2011 (G.P. Zinkann) (very roughly 50 tuners at 5000 hours/year operation)
- **Recent developments:**
  - ANL pneumatic tuner prototypes are the basis for ~200 FRIB HWR cavity tuners
  - Elliptical-cell pneumatic tuner has been tested with a 1.4 GHz Bunch Lengthening System cavity for the APS-Upgrade at Argonne

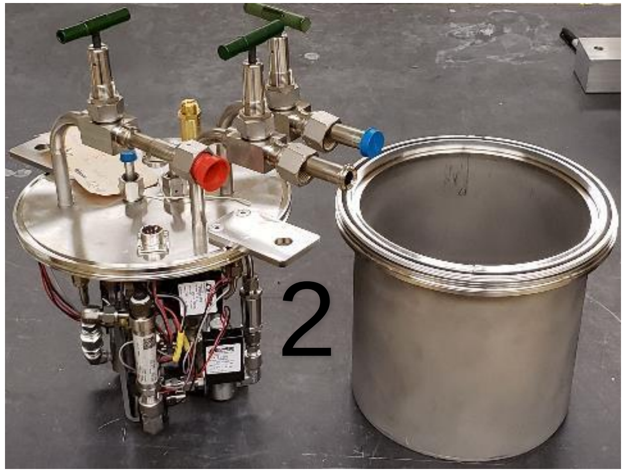
Features of the Pneumatic Tuner

- Mechanically simple, few moving parts, no mechanical feedthroughs
  - Low hysteresis, backlash, vibration
- An expandable bellows is actuated with helium gas; Bellows is the only moving part
- Bellows with helium gas typically runs at 80 K
  - Straightforward to design with low heat leak (~200 mW per cavity into 2K/4K helium)
- Large force (>10 kN) capability (bellows @ 4 atm. and ~20 cm size)
- Fast slew rate (up to 10's of kHz/s)
- Device is mechanically compliant with similar rigidity as the cavity itself (not rigid like a e-cell end lever or blade tuner)
  - Not intended to be integrated with a fast tuner

Components of ANL pneumatic slow tuner system

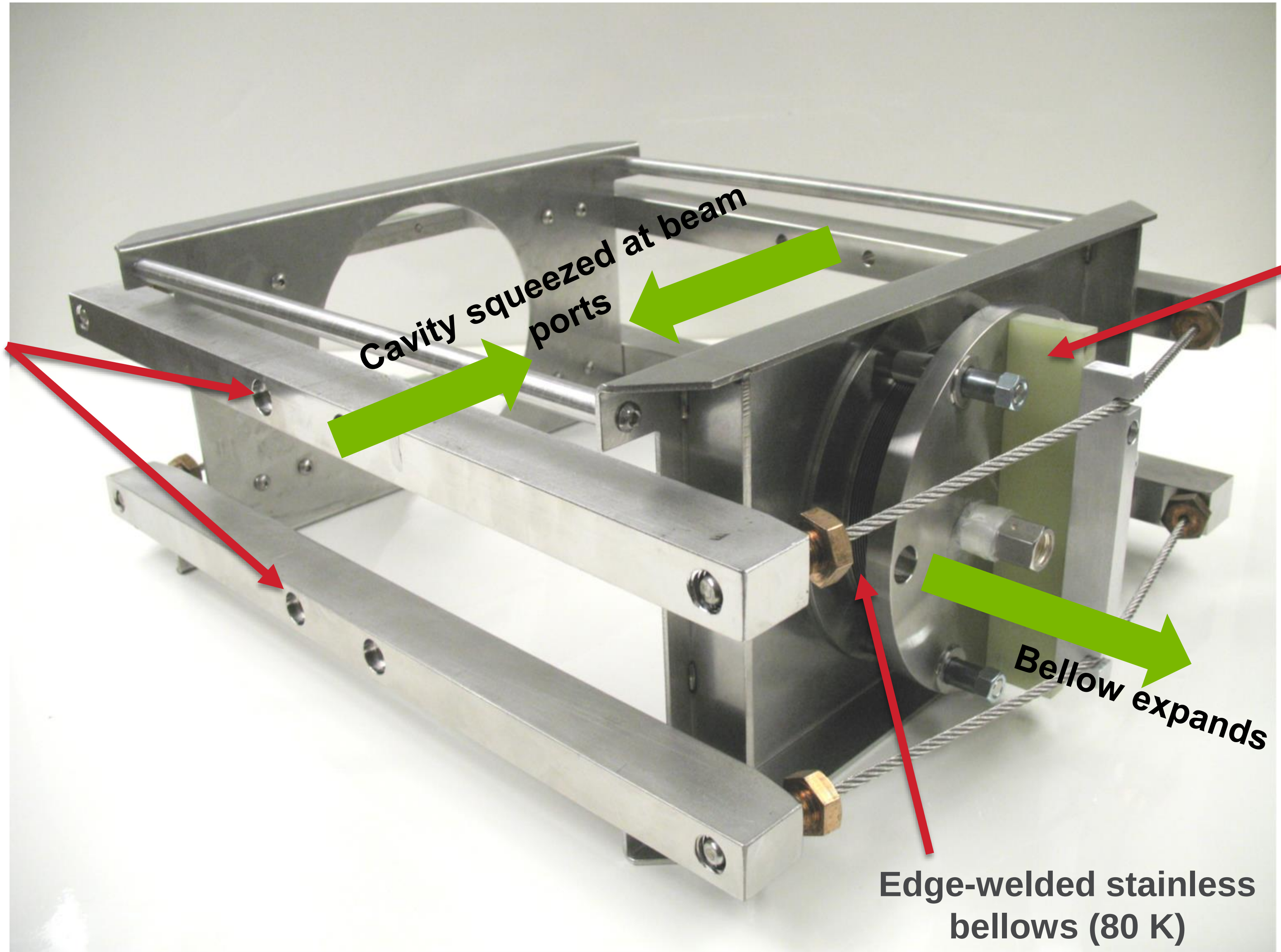






Tuner for ATLAS 72 MHz Quarter-wave Cavities
(Similar for other coaxial TEM-mode cavities, i.e. HWR)

Nitronic 60 bars attached to cavity beam port flanges (at cavity temp, 2K-4K)

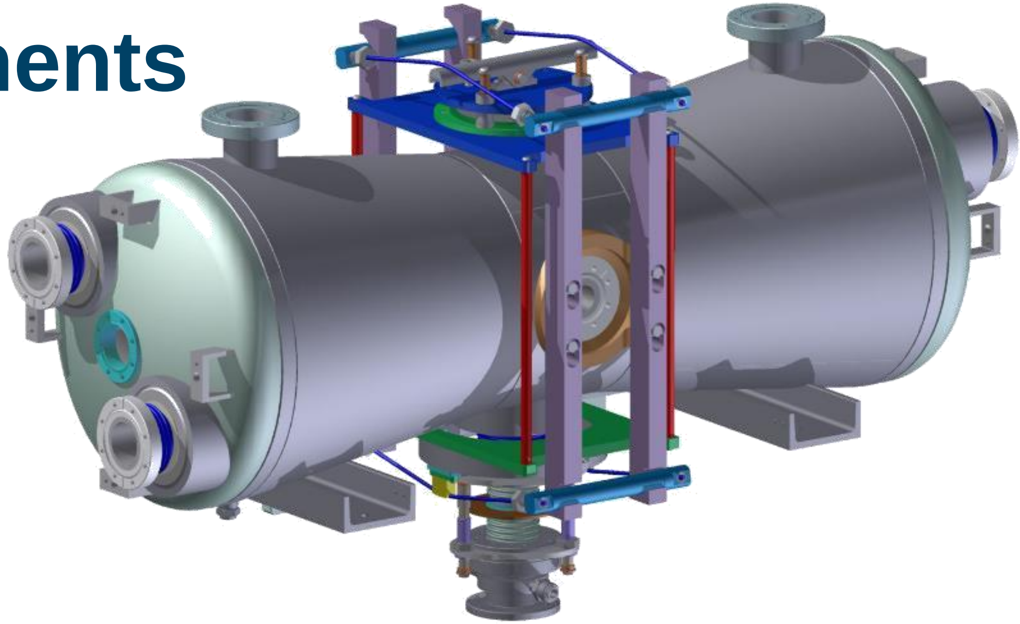


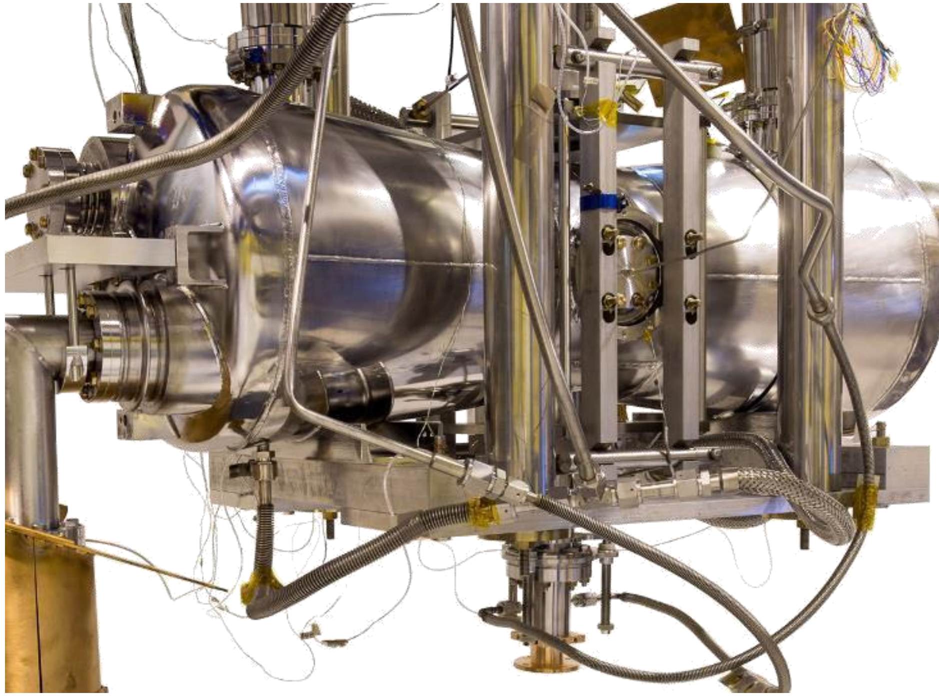
Primary thermal isolation (4 K to 80 K)

Edge-welded stainless bellows (80 K)

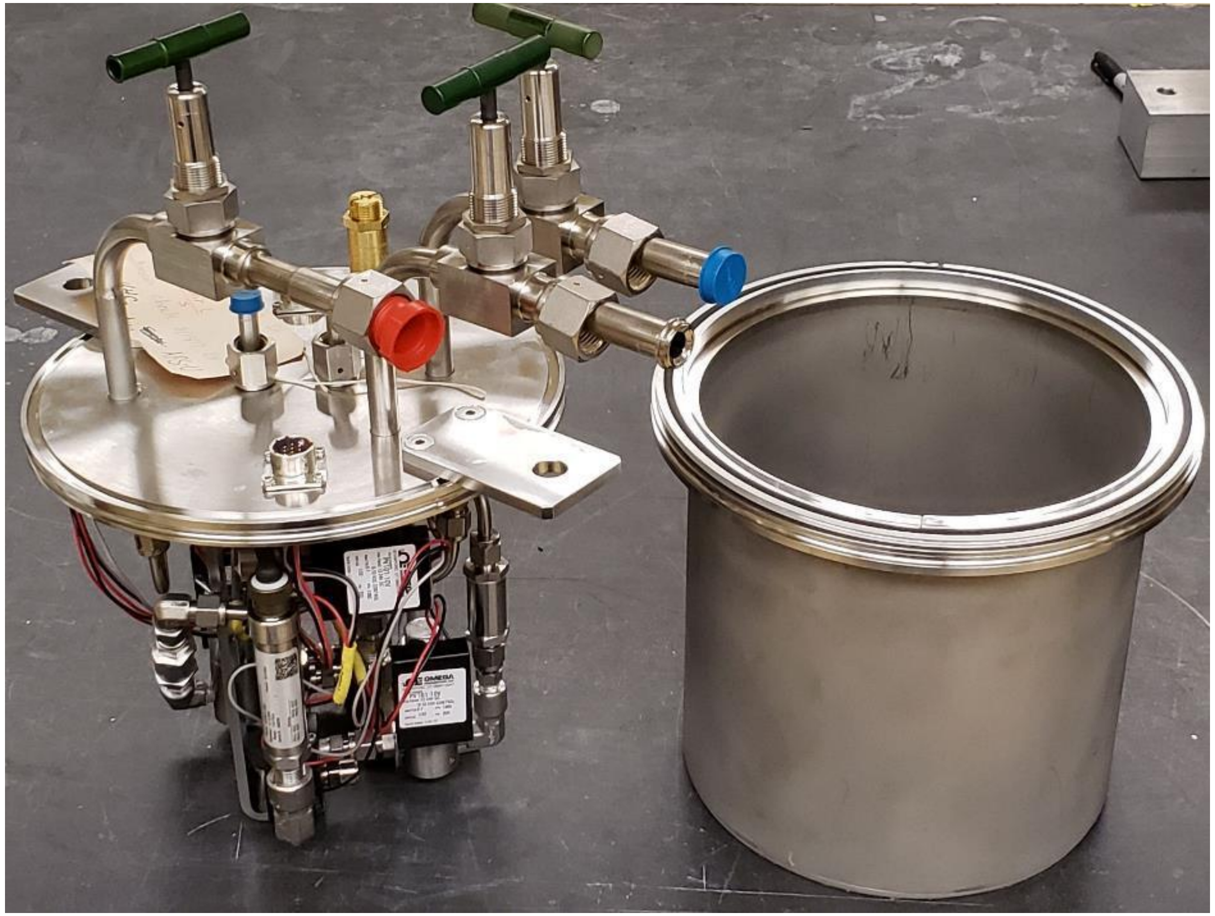
No bellows guide posts in newest tuner (similar for FRIB, photo courtesy S. Stark)

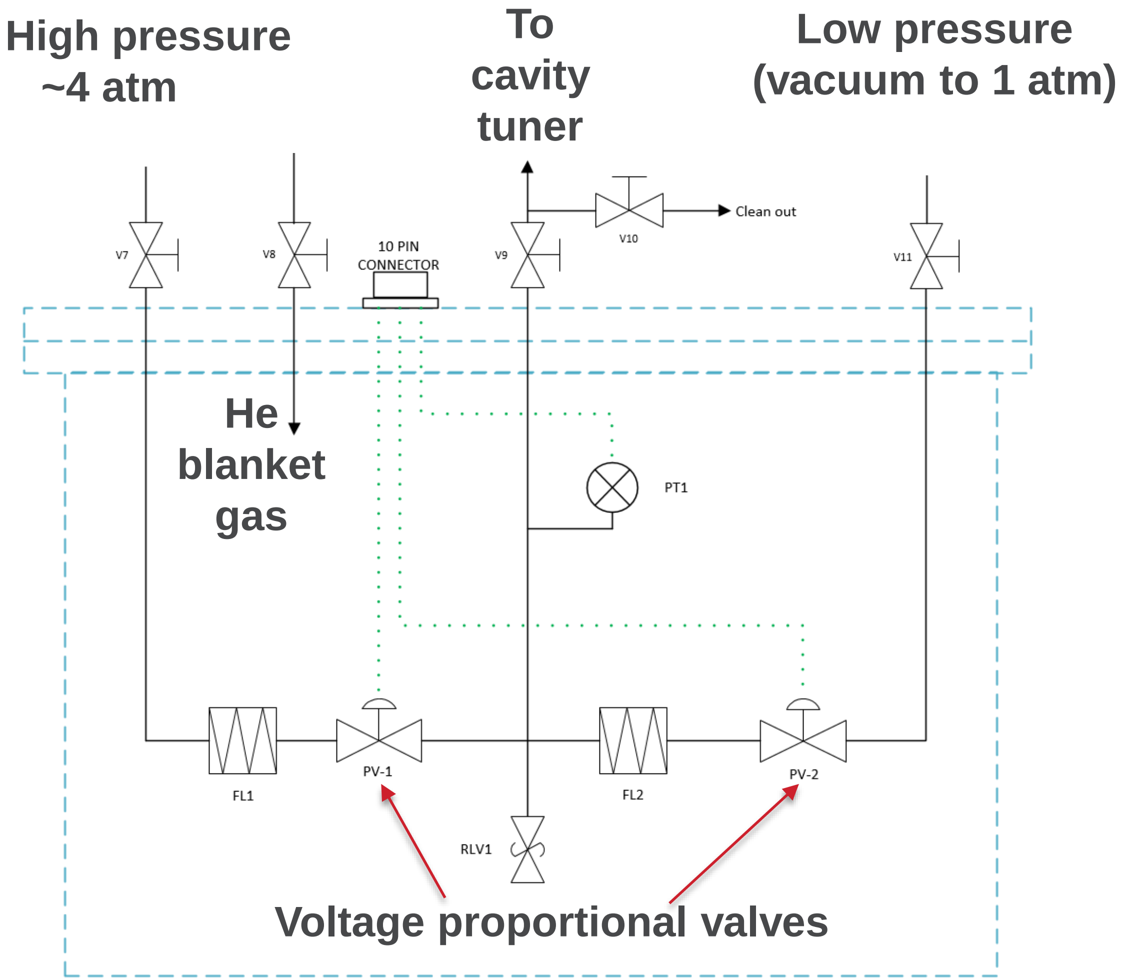
Pneumatic Tuner Subcomponents
PIP-II Half-wave Cavity





Pneumatic Tuner Gas Handling System





Example of Slow Tuner Mechanical Properties for PIP-II 162.5 MHz HWR

Parameter	Calculated Value	Measured (296K)
Δf, Slow Tuner Range (ANSYS)	130 kHz	
Required force at cavity flange	5 kN	
Force sensitivity, $\Delta f/\Delta F$	-26 Hz/N	-27.9 Hz/N
Force sensitivity, $\Delta f/\Delta x$	133 kHz/mm	119 kHz/mm
Required slow tuner frequency resolution	~1 Hz	
Slow tuner force resolution at cavity flanges	0.038 N	

Positional control at the beam port flanges of the order 10 nm!!

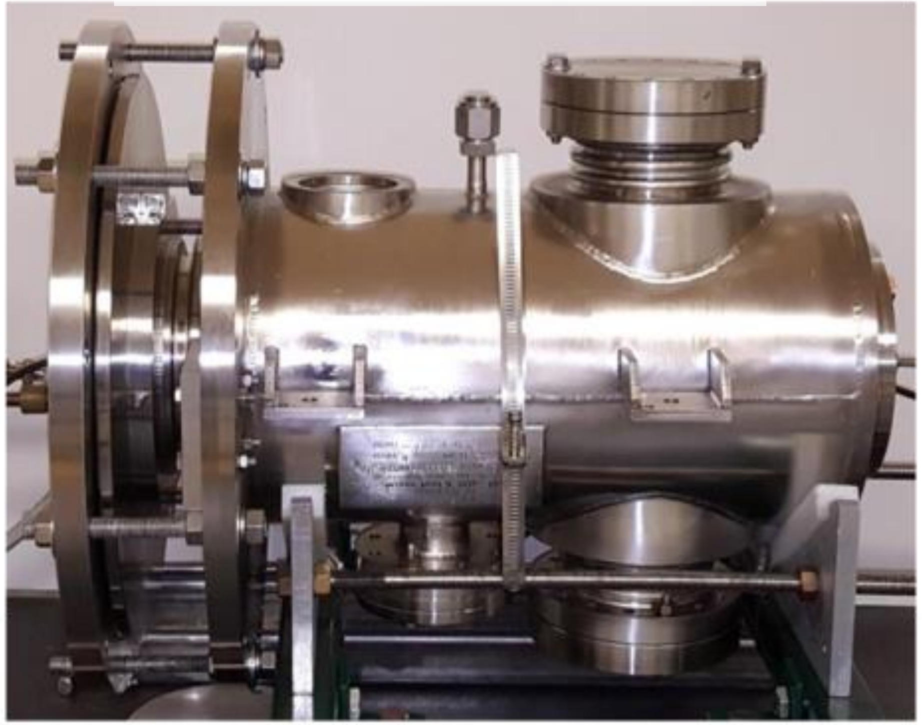
Tuner for E-cell Cavity

Single-cell Elliptical Cavity Tuner for APS-U Bunch Lengthening System

Increases the beam lifetime in the electron storage ring

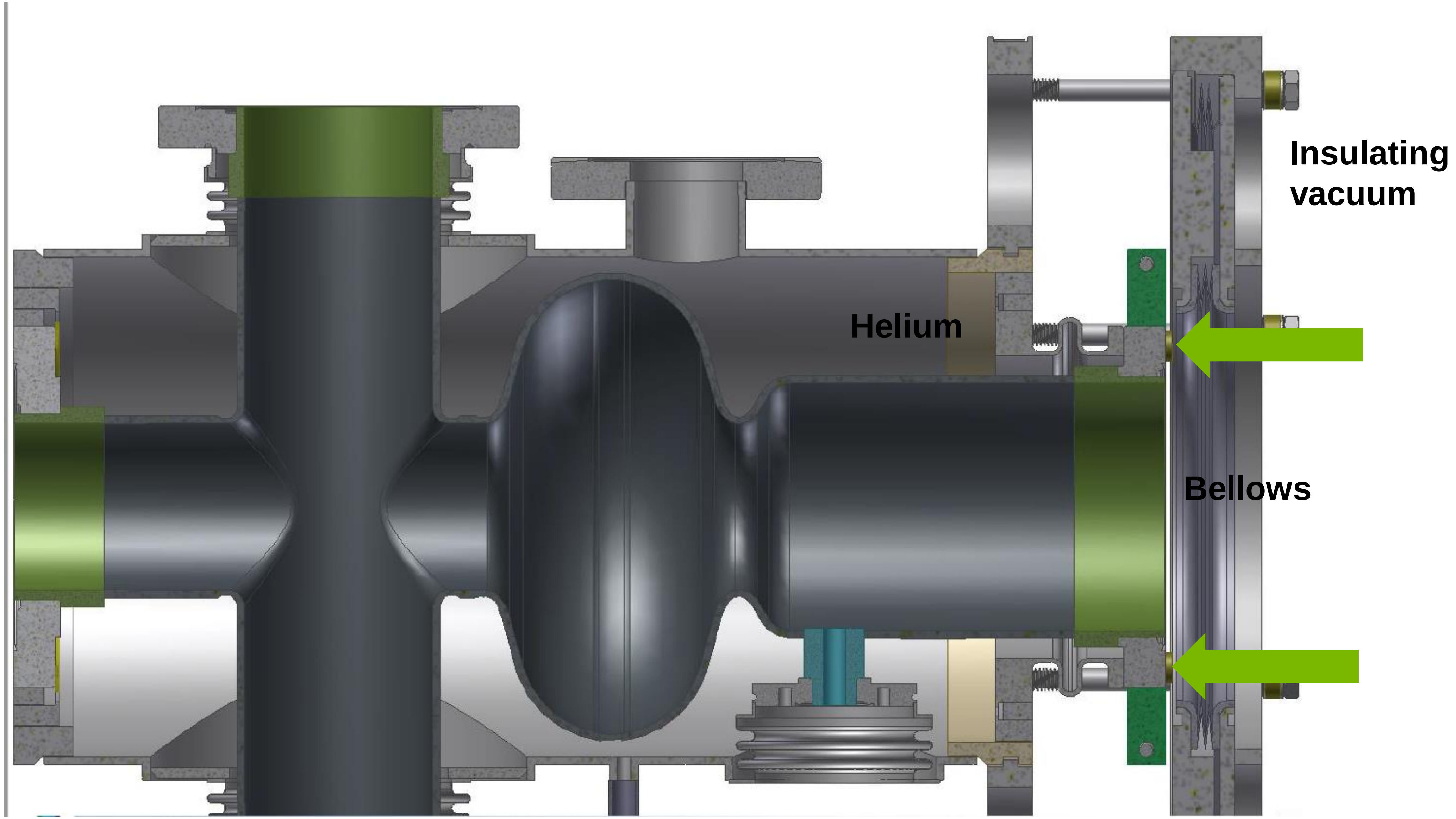
1.4 GHz SRF Cavity

Cavity with pneumatic tuner



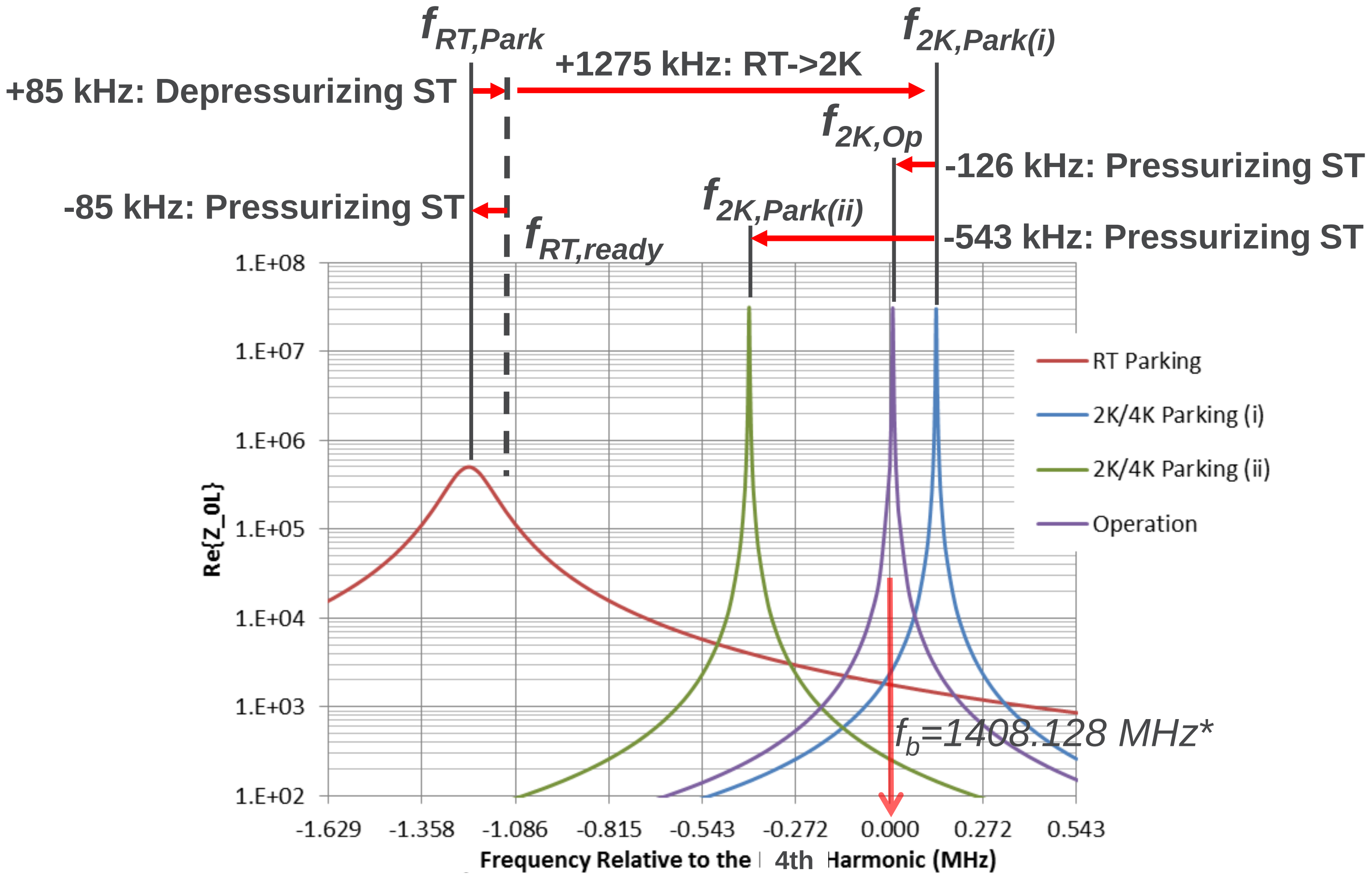
Cross Section of Elliptical Cavity with Pneumatic Tuner

R&D program on BLS technical systems is complete (May 2017)



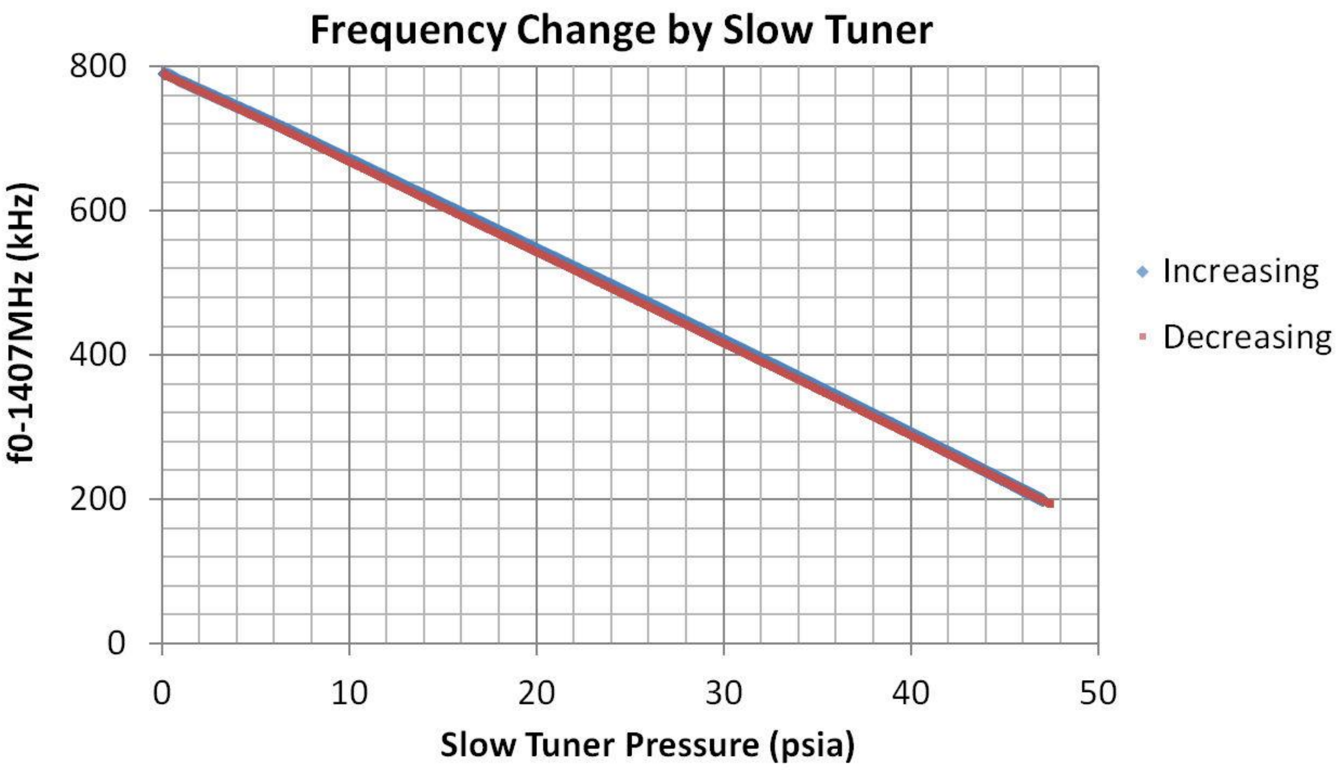
Cavity Operation Modes Using Pneumatic Slow Tuner

$f_{2K,Park(i)} = f_b + 136\ kHz$: 1/2 revolution frequency higher than the 4th harmonic
$f_{2K,Park(ii)} = f_b - 407\ kHz$: 1-1/2 revolution frequency lower than the 4th harmonic
$f_{RT,Park} = f_b - 1.22\ MHz$: 4-1/2 revolution frequency lower than the 4th harmonic at RT



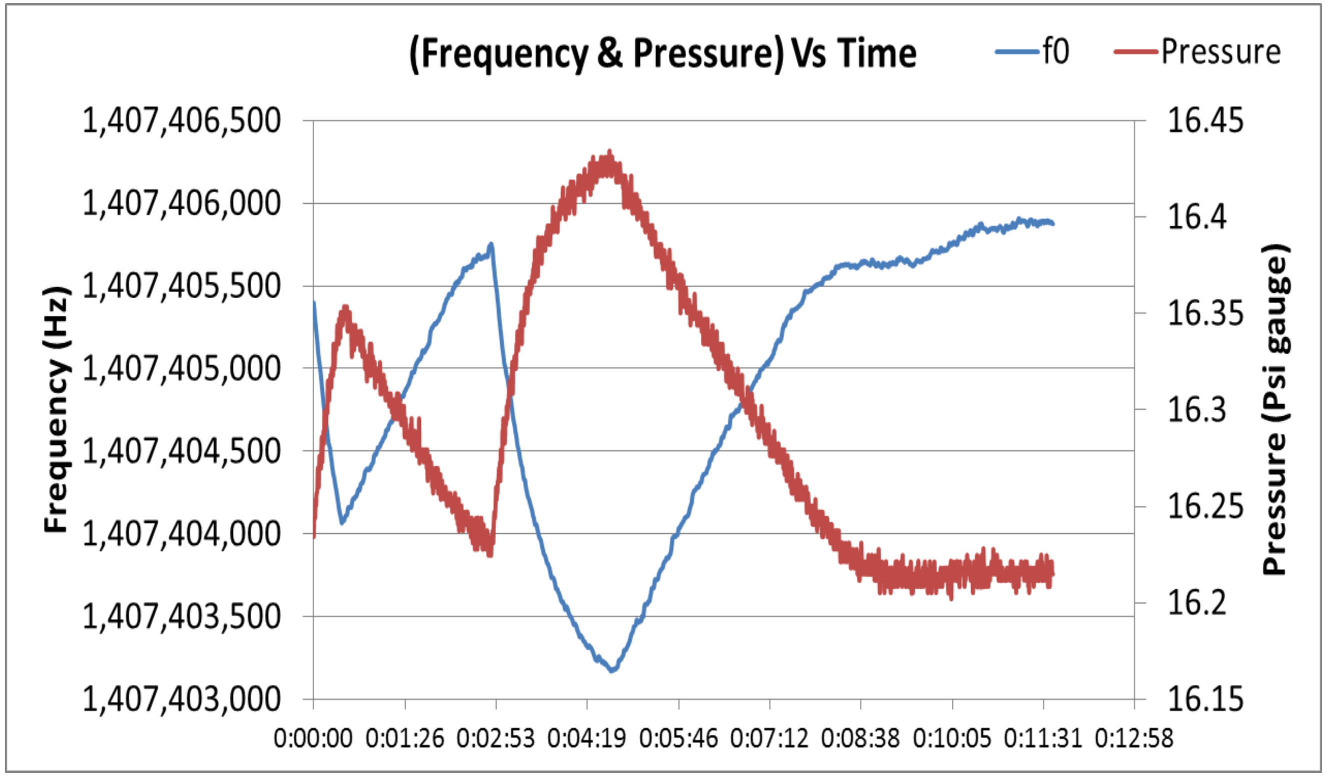
- Harmonic Voltage
  - **0.1 MV** @ 2K/4K Parking(i)
  - **36 kV** @ 2K/4K Parking(ii)
  - **12 kV** @ RT Parking
- Wall Dissipation Power
  - **10 mW/0.6 W** @ 2K/4K Parking(i)
  - **1 mW/0.06 W**@ 2K/4K Parking(ii)
  - **140 W** @ RT Parking

Open-loop full range measurement on APS-U cavity



The first cycle of increasing and decreasing pressure is analyzed for hysteresis. The 600 kHz range is plotted against the 50 psi pressure change. Increasing pressure is plotted in blue and decreasing pressure is plotted in red.

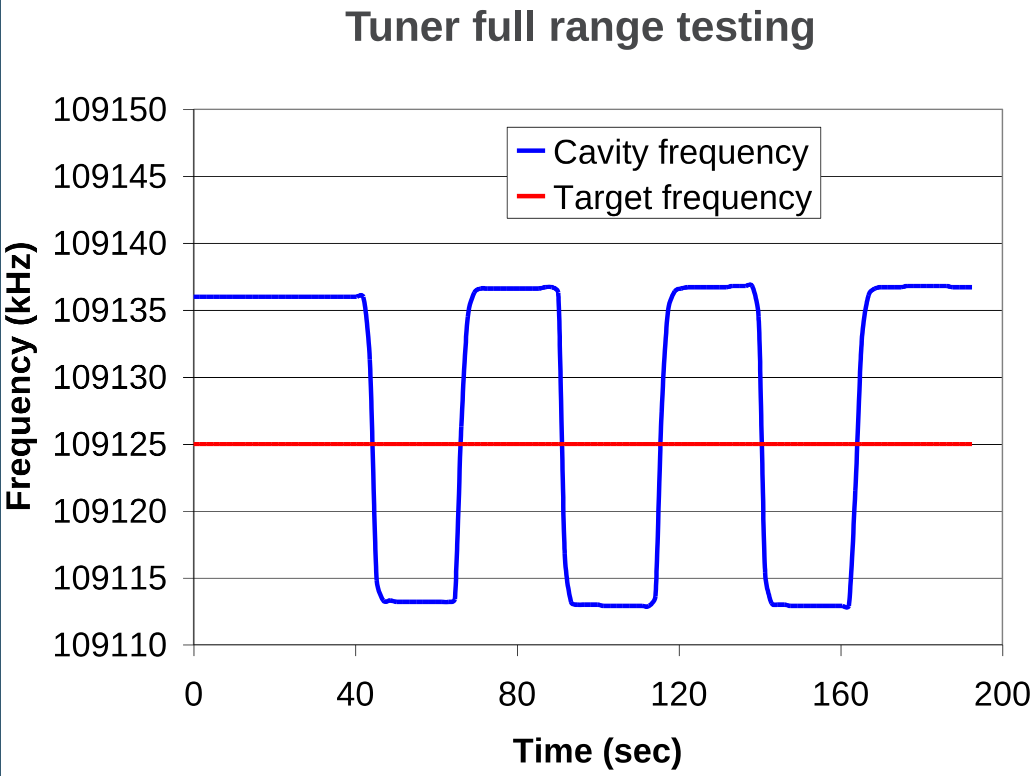
Open-loop tuner measurements on APS-U cavity Look for any ‘step-wise’ behavior

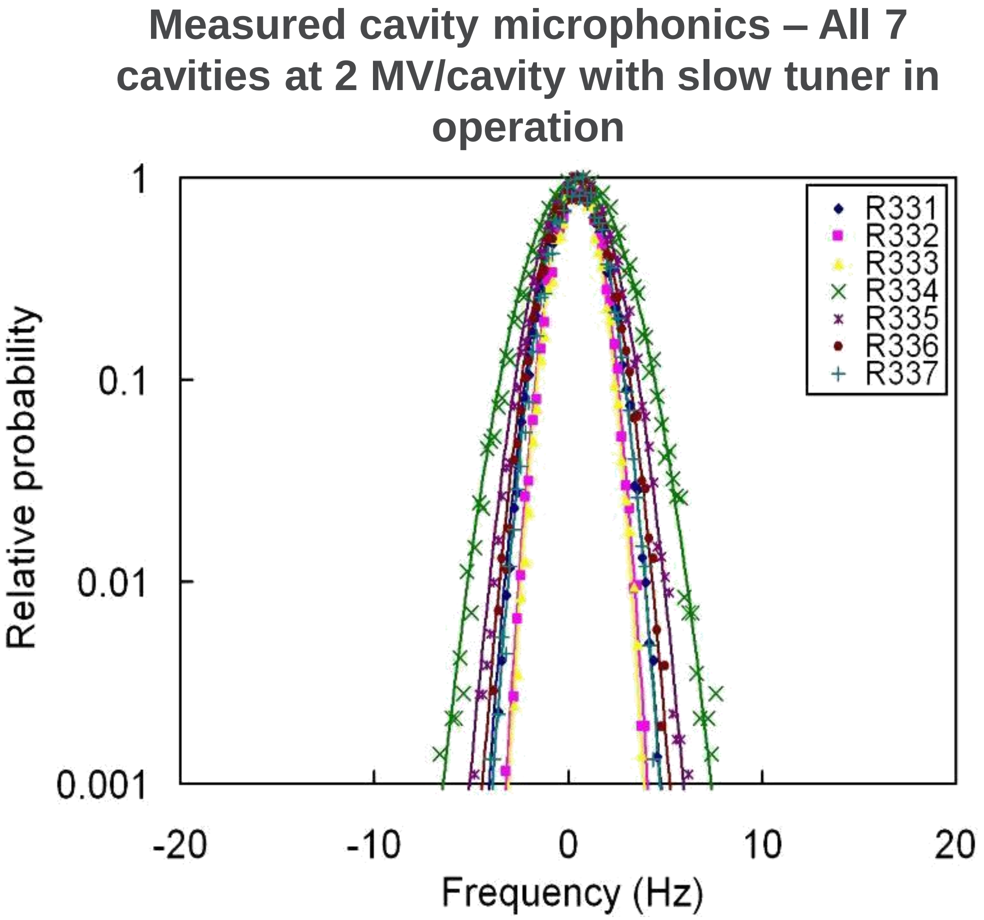


Slow tuner open loop response to small changes in tuner pressure (red) applied manually with a gas bottle: The vertical frequency scale covers 2.5 kHz. The applied pressure change was 0.2 psi.

Tuner response is smooth with no step-wise behavior at a level of better than 100 Hz

Example: Tuner and Microphonics Data for 109 MHz QWR Cryomodule (2009)

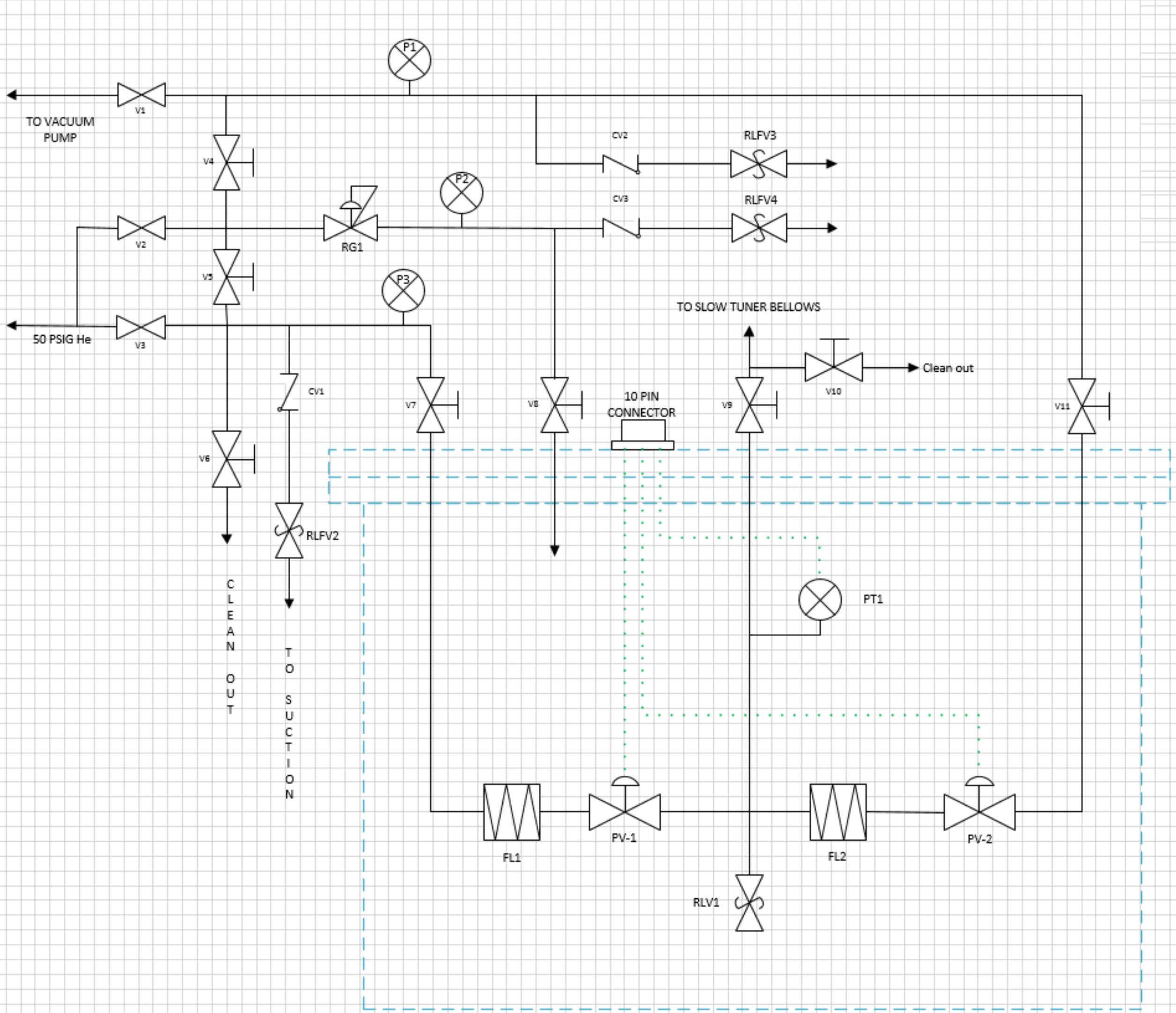




Final Comments

- Key features: mechanical simplicity, low microphonics
- Limitations: not many; perhaps difficult to directly integrate a piezo tuner
- 4 decades in ATLAS with good reliability and maintenance record
- Can be designed for low heat leak into 2 Kelvin
- Experience has been with low-beta (TEM-mode) cavities
  - Appears equally suitable select e-cell applications

Backup: Slow Tuner PID



LABEL	DISCRIPTION	VALUE
VI	VALVE	
V2	VALVE	
V3	VALVE	
V4	VALVE	
V5	VALVE	
V6	VALVE	
V7	VALVE	
V8	VALVE	
V9	VALVE	
V10	VALVE	
V11	VALVE	
CV1	CHECK VALVE	1/3 psig
CV2	CHECK VALVE	1/3 psig
CV3	CHECK VALVE	1/3 psig
RLRV1	RELIEF VALVE	50psig
RLRV2	RELIEF VALVE	55psig
RLRV3	RELIEF VALVE	5psig
RLRV4	RELIEF VALVE	10psig
PV1	PROPORTIONAL VALVE	0-10V
PV2	PROPORTIONAL VALVE	0-10V
FL1	FILTER	.5 micron
FL2	FILTER	.5 micron
PT1	PRESSURE TRANSDUCER	
P1	PRESSURE GUAGE	-45
P2	PRESSURE GUAGE	0-15 PSI
P3	PRESSURE GUAGE	0-10PSI
RG1	REGULATOR	5PSIG