Status of ARIEL E-LINAC CRYOMODULES

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TRIUMF

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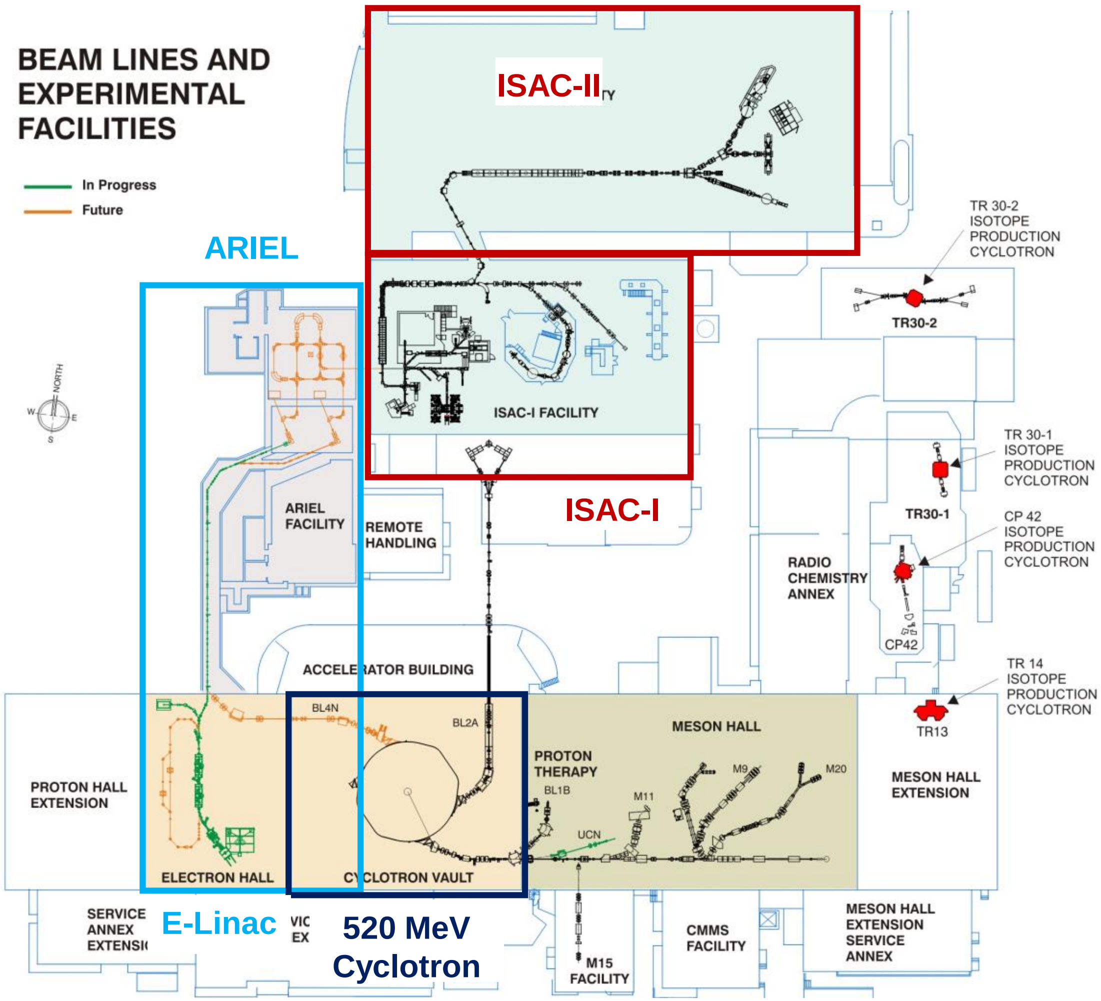
Discovery, accelerated

Outline

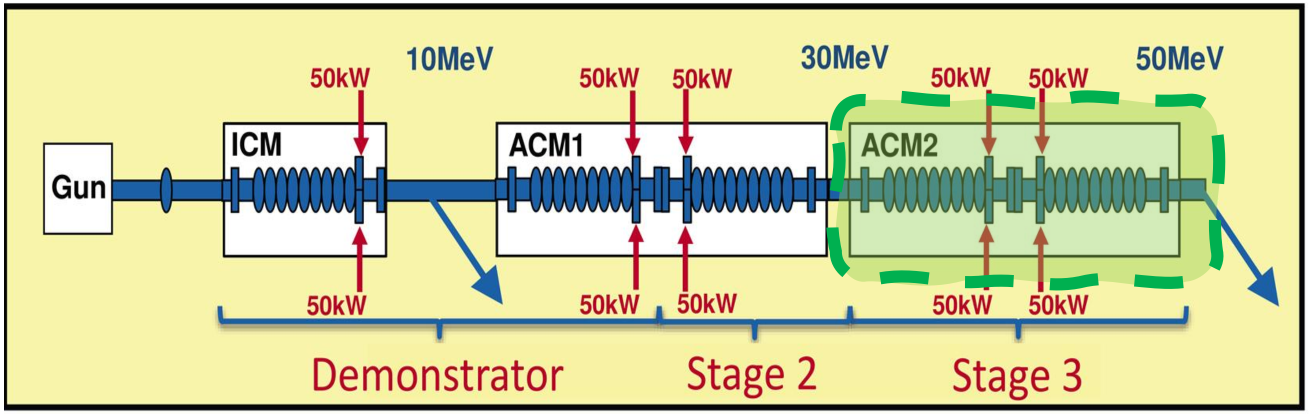
- Overview of ARIEL e-Linac
- Cryomodule online performance
- Microphonics compensation
- Discussion

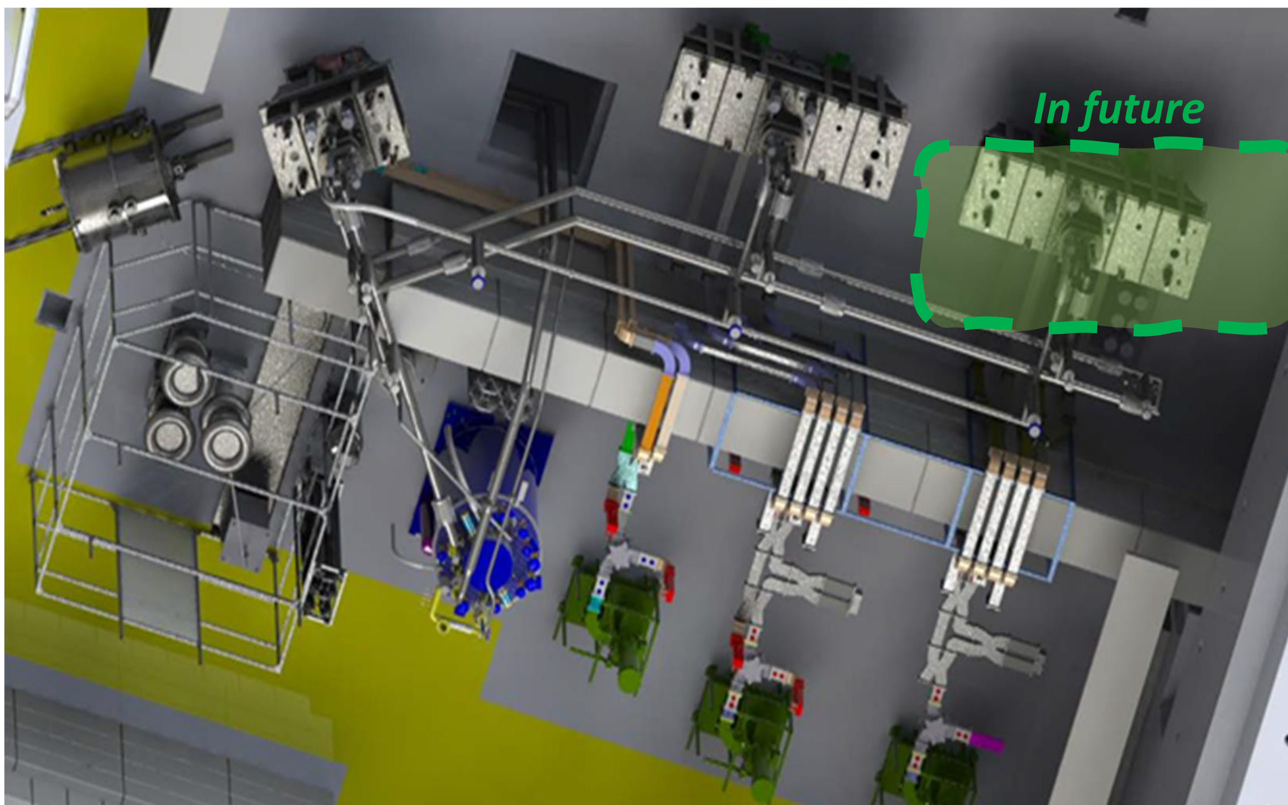
Overview of ARIEL



- Provide three simultaneous radioactive ion beams (RIB)
  - 1 beam from e-Linac+2 beams from cyclotron
- New complimentary driver (e-linac)
  - Creates RIBs through Photo-Fission
  - 30 MeV, 3 mA, CW Superconducting e-Linac
- Target area ready in 2024

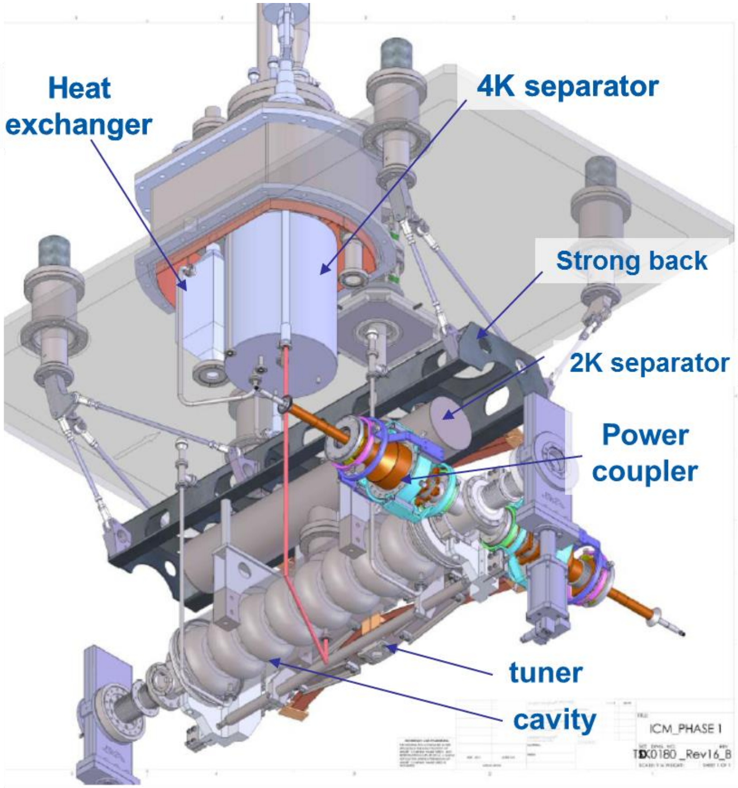
Overview of ARIEL e-Linac

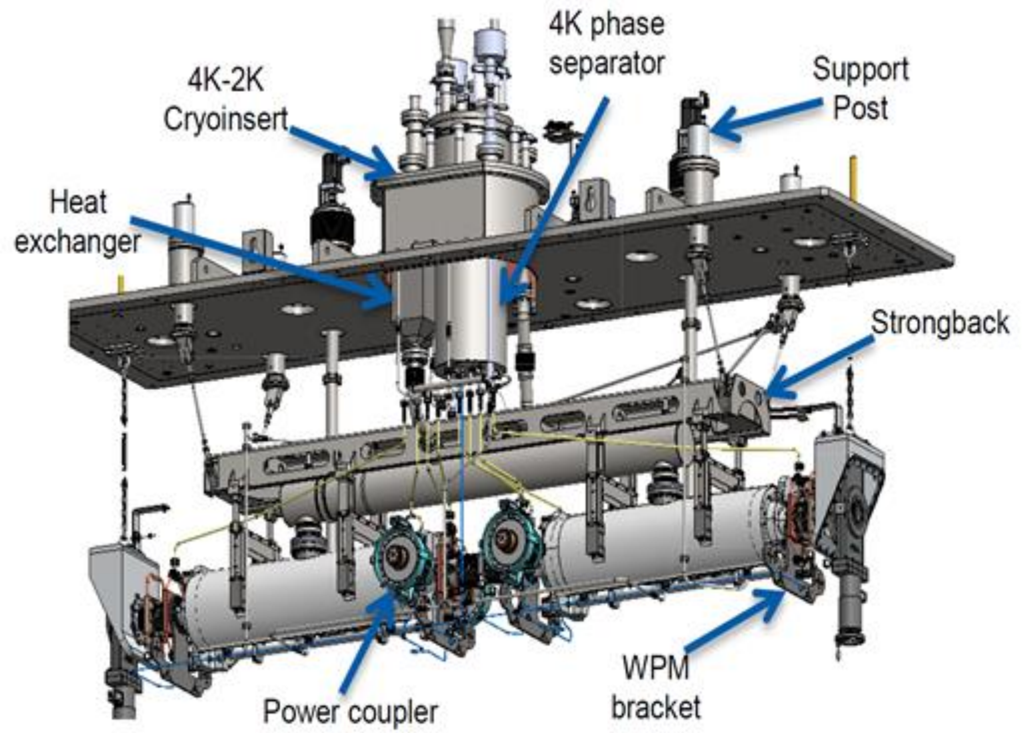




- 23 MeV demonstrated from 2 cavities in 2014
- A 3rd cavity installed in 2017
- 25 MeV achieved in 2018
- 31 MeV achieved in 2019
- 1kW beam delivery achieved in 2020
- 10kW beam delivery in 2021
- 100kw beam delivery in 2024

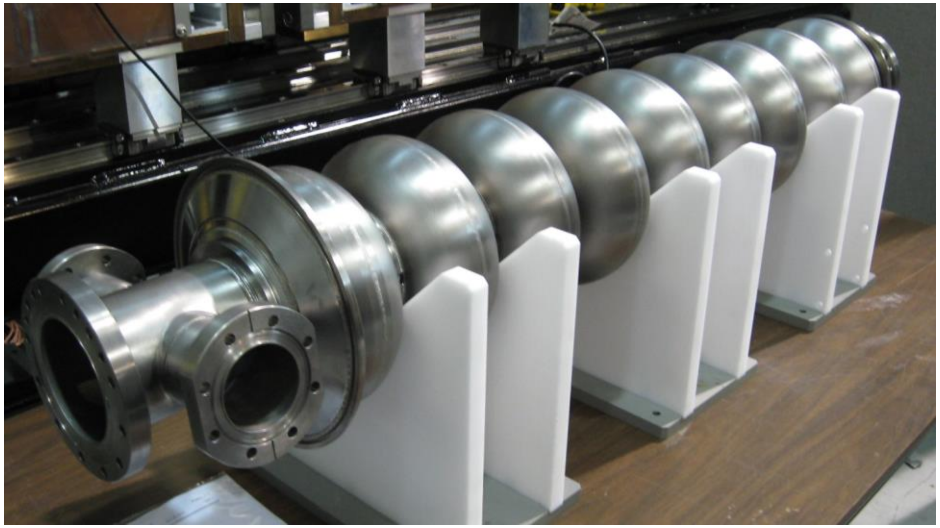
Cryomodules

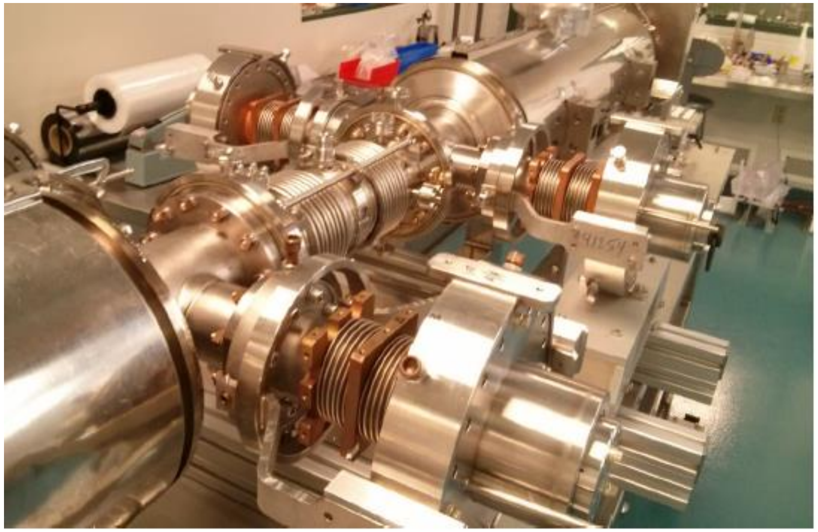




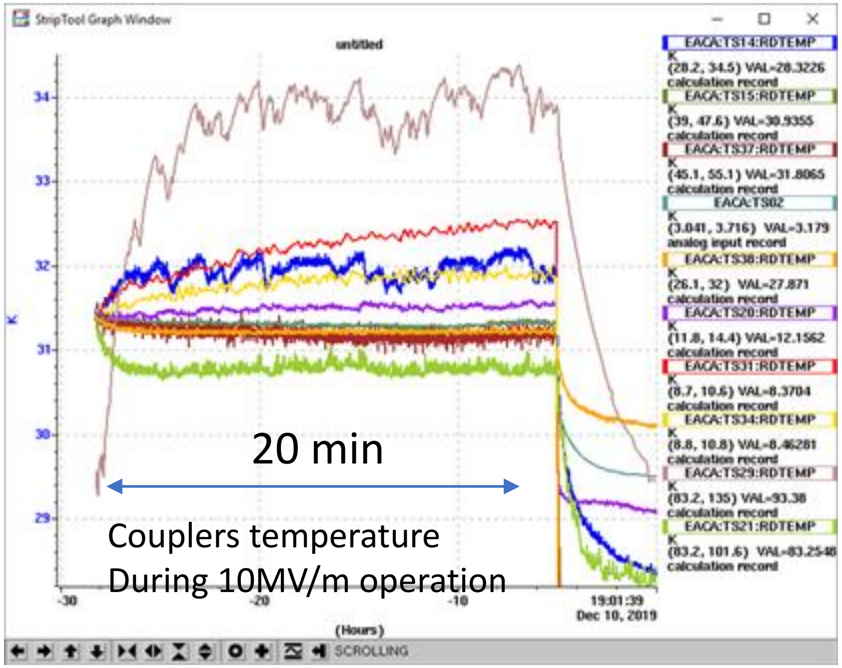
- ***Box cryomodule with a top-loading cold mass;***
  - One/two nine-cell 1.3GHz cavity
  - Two/four 50kW power couplers
  - HOM coaxial dampers
- ***4K/2K heat exchanger unit with JT valve on board;***
- ***Scissor tuner with warm motor;***
- ***LN_2 cooled thermal shield;***
- ***4K intercepts cooled by syphon circuit from 4K tank;***
- ***2 layers mu-metal shield***
- ***WPM alignment system***
- ***ICM 2K static load is 5.0W***
- ***ACM1 2K static load is 10.9W***

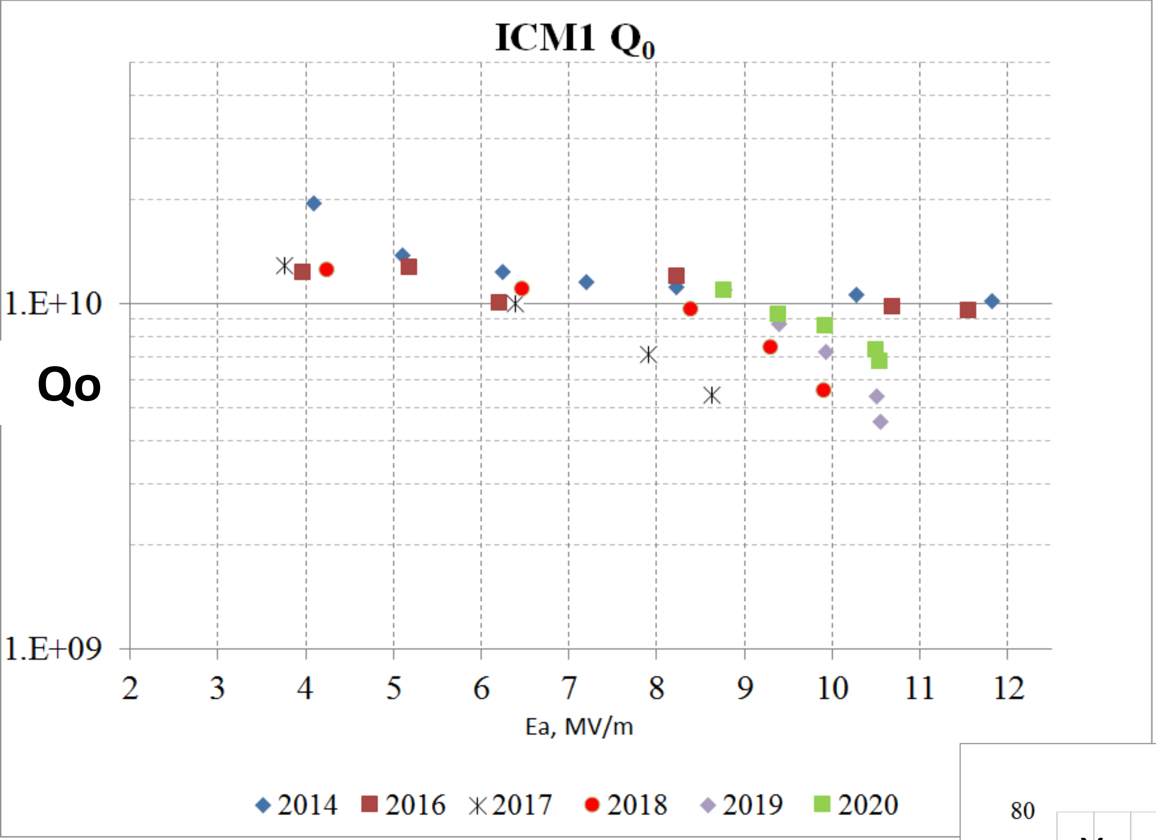
Cavity and coupler



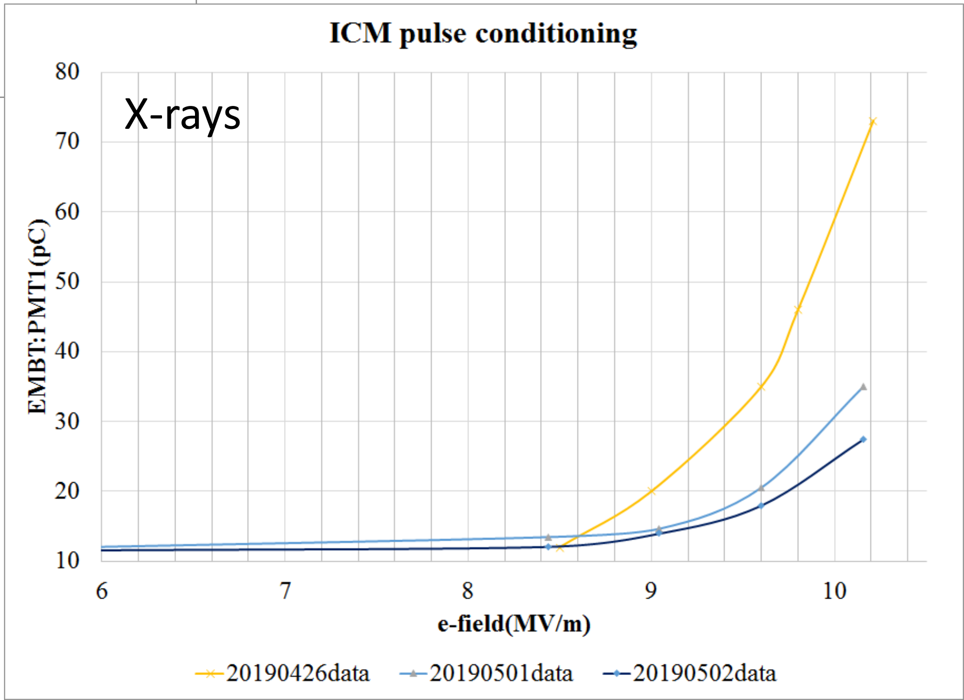


- 1.3 GHz 9-cell elliptical cavity
  - End groups modified to accommodate 2 couplers and to reduce trapped modes
  - CESIC and Stainless Steel coaxial HOM dampers
  - Operates at 10 MV/m cw
- CPI VWP 3032 Coupler
  - All couplers have been baked and conditioned before installation
  - All couplers work well
    - Vacuum and temperatures are stable

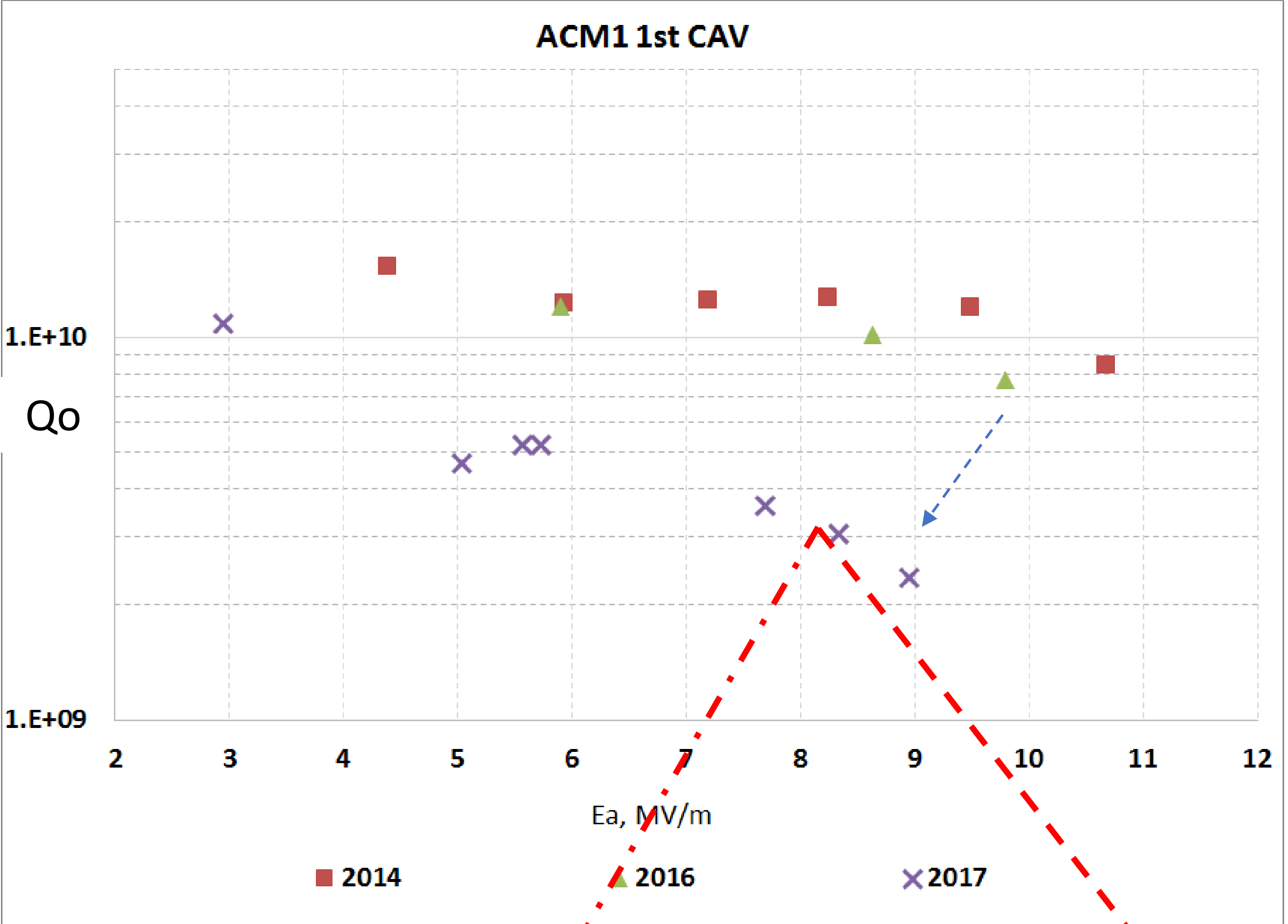




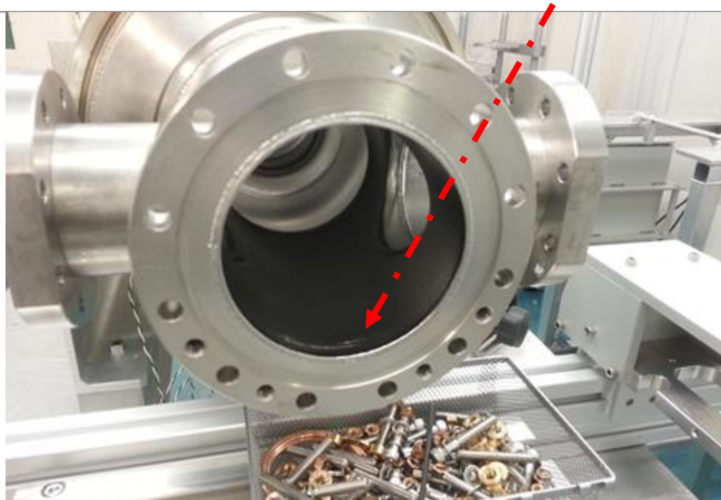
- ICM Q_0 deterioration due to inadvertent pressure event in 2017
- ICM will be reprocessed in 2021
- Venting hardware added to prevent further mistakes

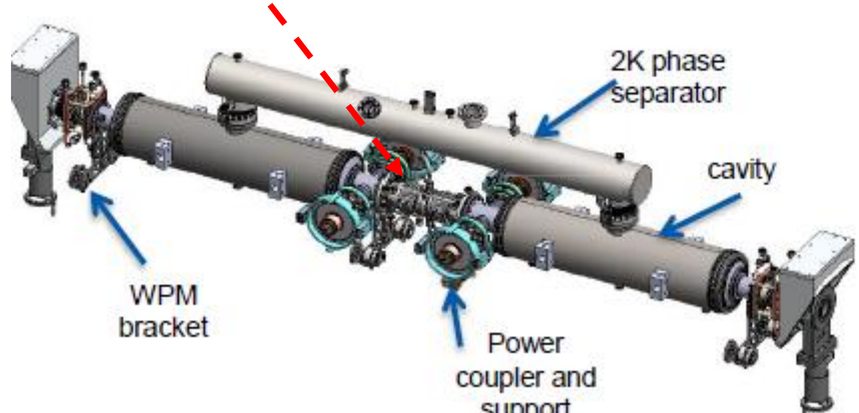


- Field emission controlled by high power pulse conditioning
  - Strong field emission at 10MV/m
  - Now ICM is running around 8MV/m to reduce the x-ray level and avoid tripping Machine Protection System(MPS)

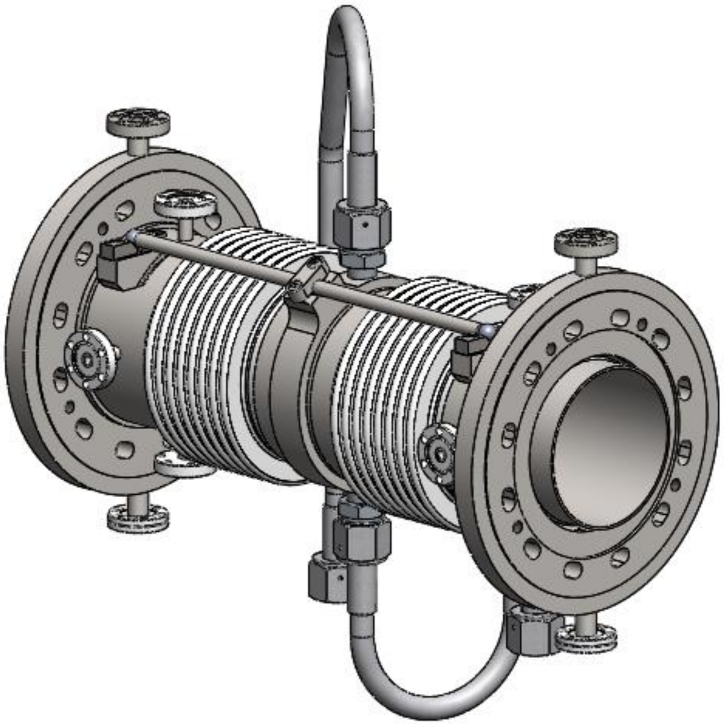


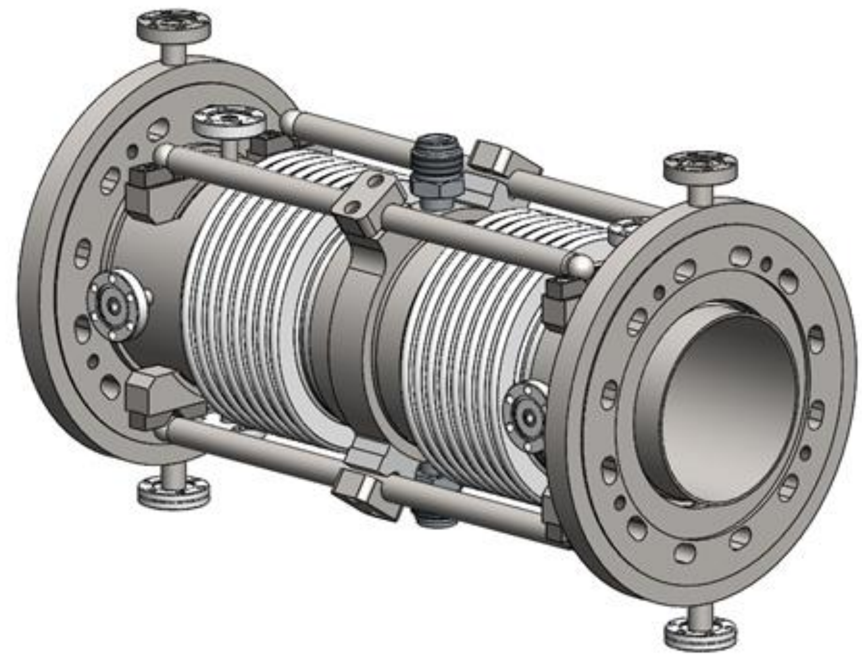
- The 2nd cavity of ACM1 was installed in 2017
- During the two cavity test, 1st cavity showed very low Q_0
- SS damper that fits inside the cavity at the coupler end touched down on the Nb cavity causing scoring
- Reprocessed in 2018





ACM1 Inter-cavity HOM Damper

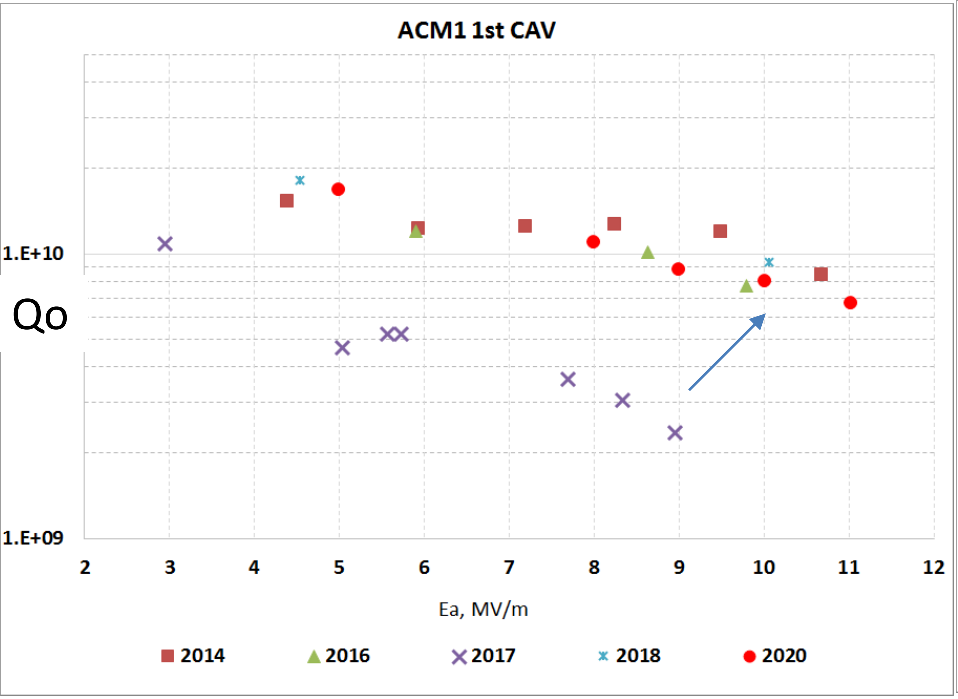


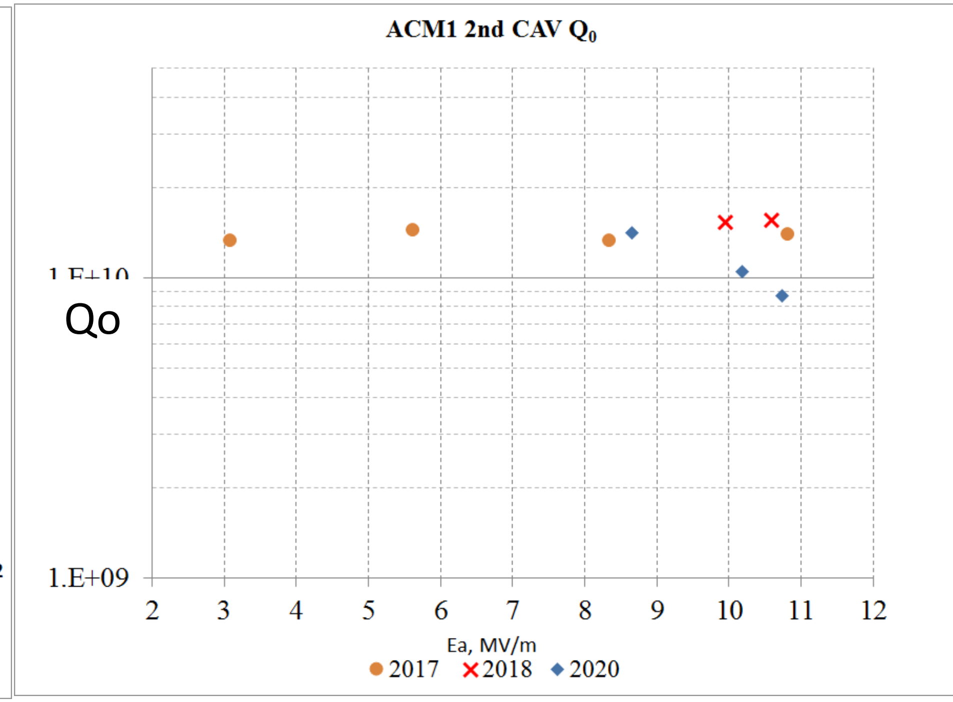


	mm
Beam tube ID	96
Damper OD	91
Clearance (around)	2.5
ACM Inter-cavity Transition Flange-to-Flange length	360.4
Damper Length	381.6

- There was only one rod to keep the damper and cavities aligned
- The rod was not strong enough to keep the alignment during cooldown.
- Use the same ball and rod concept, but with 4 x ½" rods

ACM1 Cavity performance by year

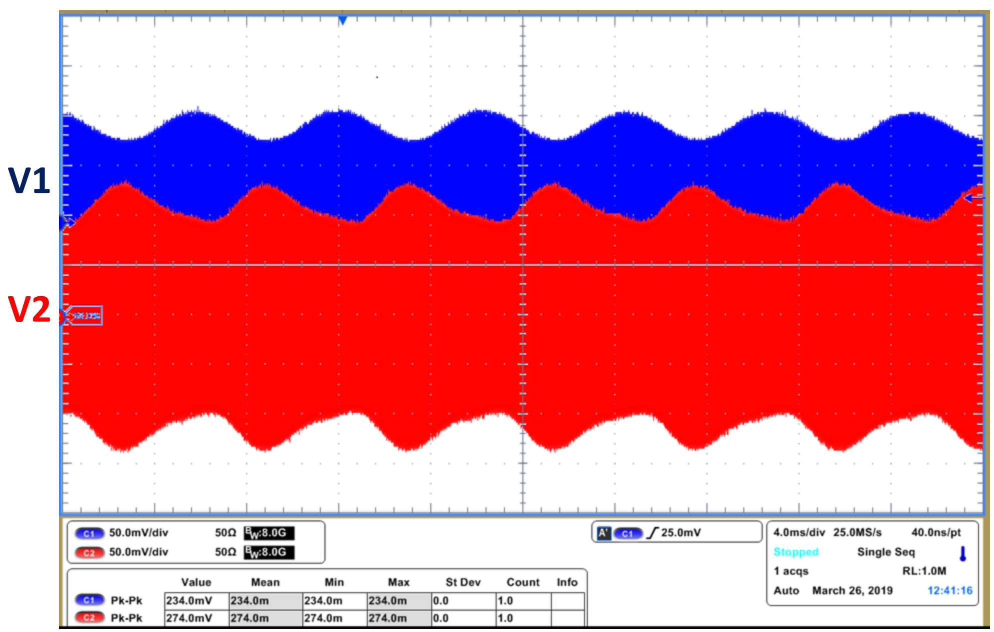


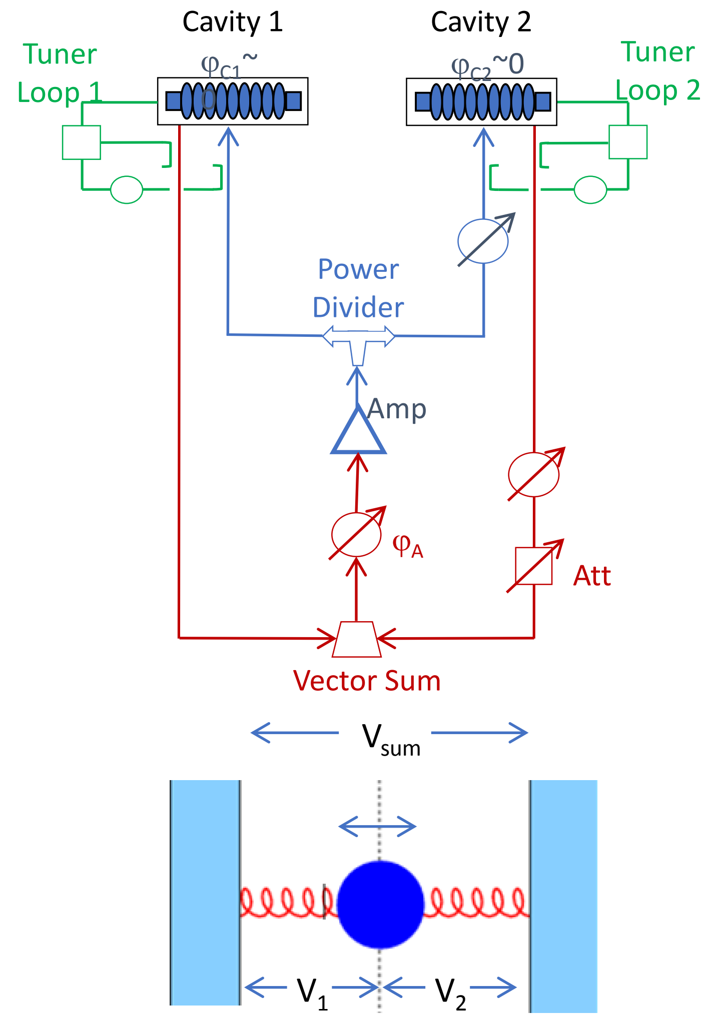


- After reprocessing ACM1, 1st cavity Q_0 recovered
- Both of ACM1 cavities show Q_0 deterioration with time

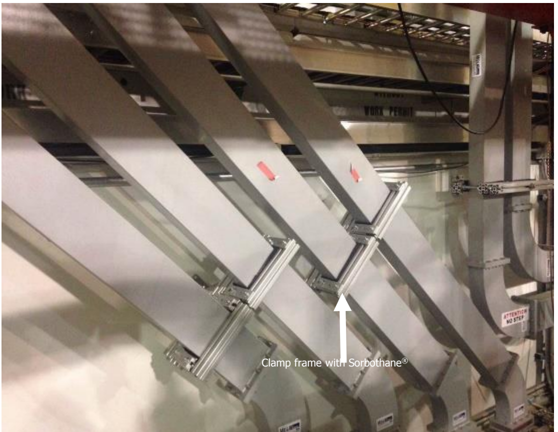
ACM1 RF Stability

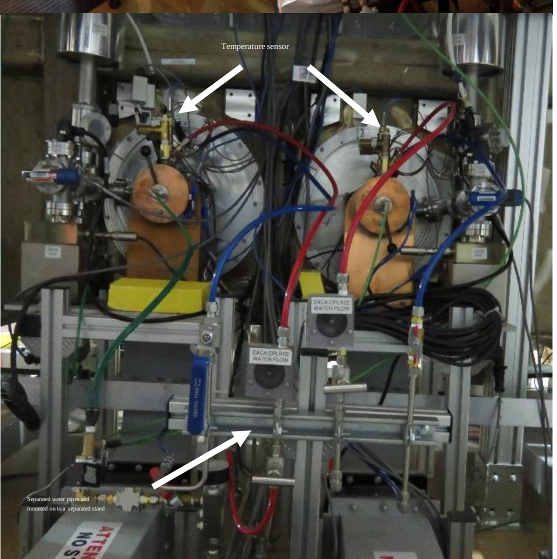
- ACM1 cavities are driven by a single klystron in Vector Sum
- Under certain conditions, individual cavity voltages can oscillate in counterphase causing an instability in the beam energy
    - The instability is driven by coupling between cavity mechanical vibrations and `the Lorentz force
    - Mitigation: 1. reduce microphonics 2. appropriate choice of detuning parameters 3. add piezos to tuner stack

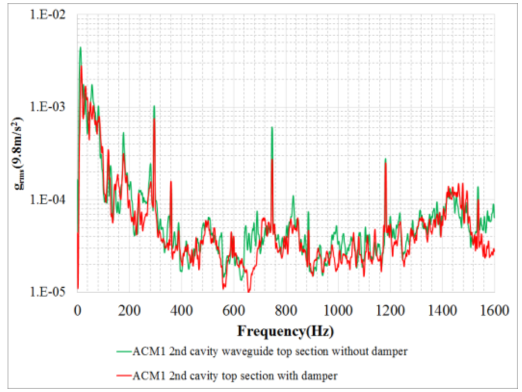


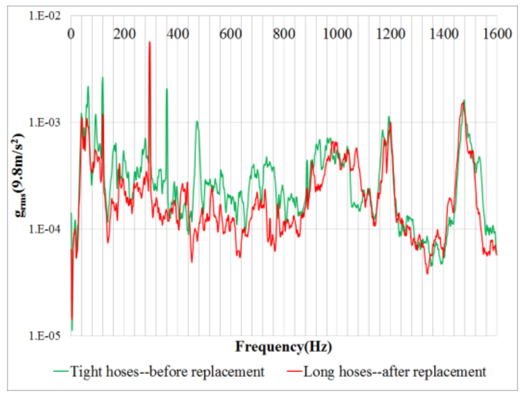


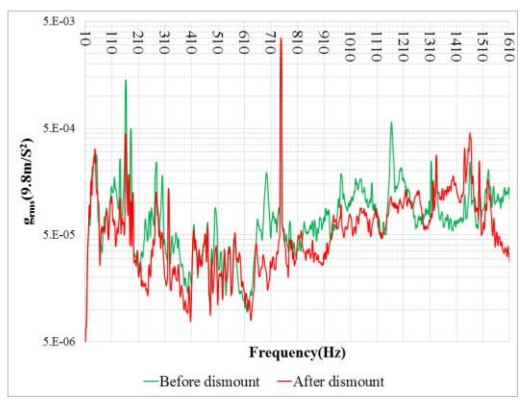
LLRF compensation and mitigation of two cavity instability. Ramona LEEWE ,TTC2019,Vancouver











Microphonics Suppression

RF Waveguide system

- ✓Anchored waveguide support and klystrons
- ✓Damped waveguide parts and dummy loads
- ✓Replaced tight hoses
- ✓Separated hoses and SS pipes from the waveguide support

RF couplers cooling air

- ✓Added a temperature sensor (OS36-T-140F) for each coupler warm window
- ✓ Reduced the air flow rate

Cryomodule vacuum system

- ✓Turned off Turbo pumps and roughing pump at 2K

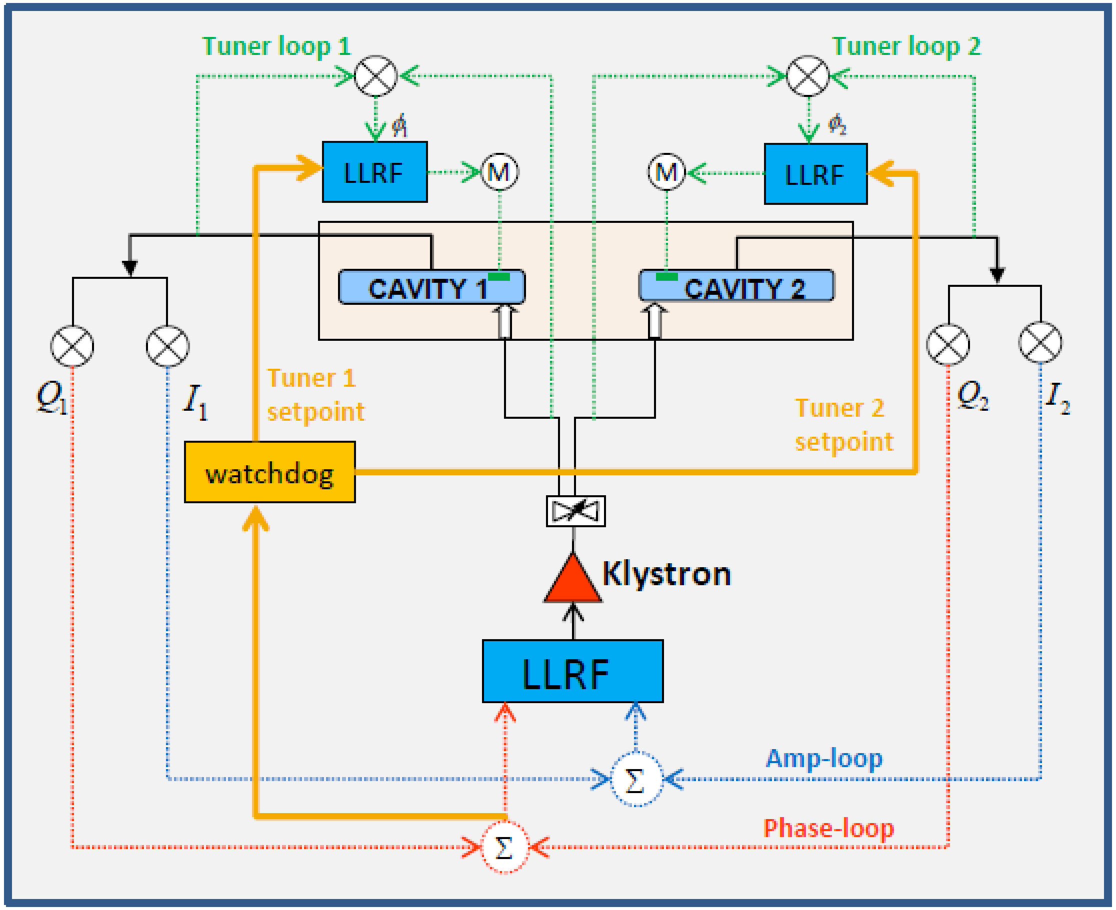
LN system upgrade

- ✓Added a flow proportional valve for level regulation in phase separator
- ✓Regulated cryomodule LN2 supply valves from the RF coupler LN2 intercept temperatures
- ✓PID control loops optimized

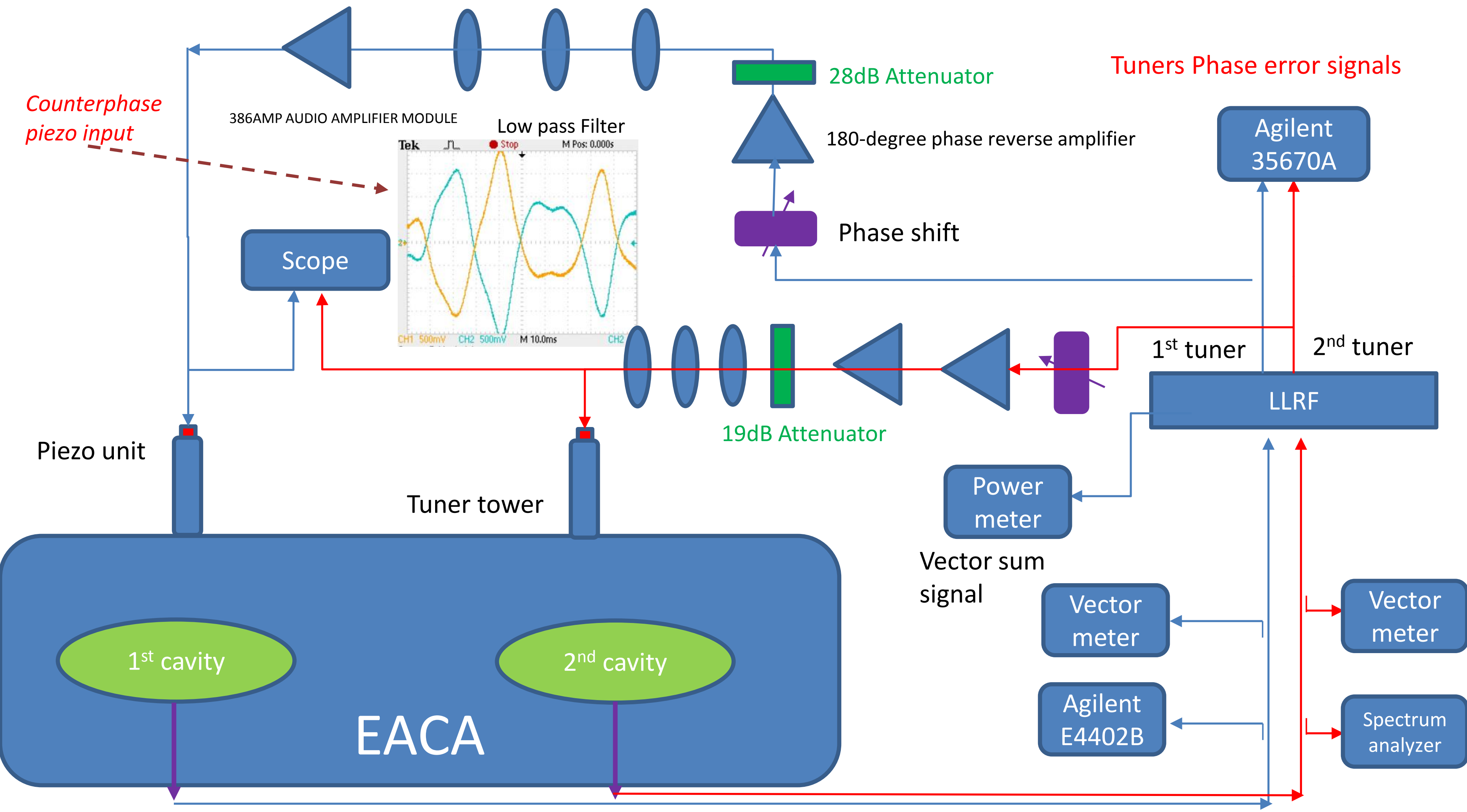
Watchdog

Added '*watchdog*'

- Monitor the Vector Sum phase loop drive
- Watchdog changes the 'tuner setpoints' that determine the detuning in each tuner loop
- Maintains the phase loop drive in the stable region of phase space



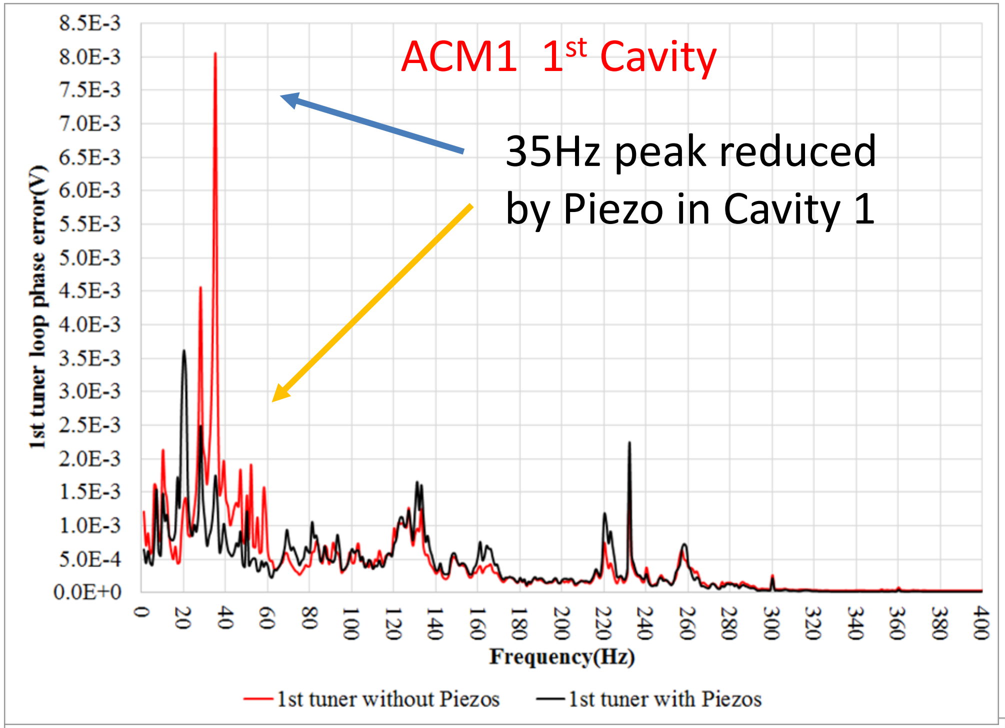
Control Piezos through ACM1 LLRF tuner loop drives

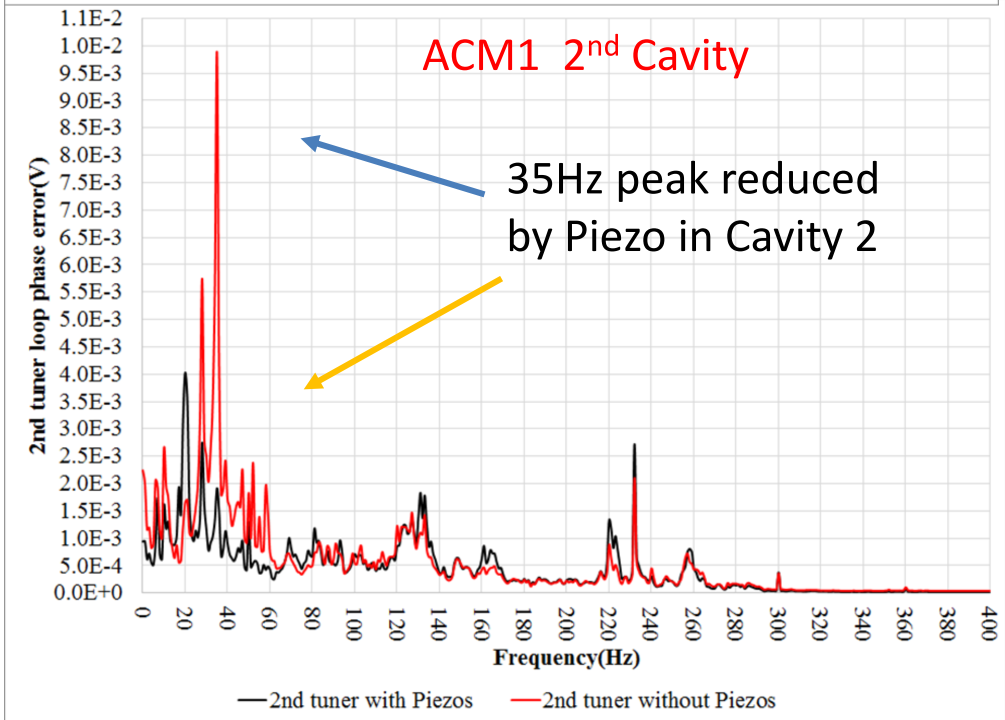


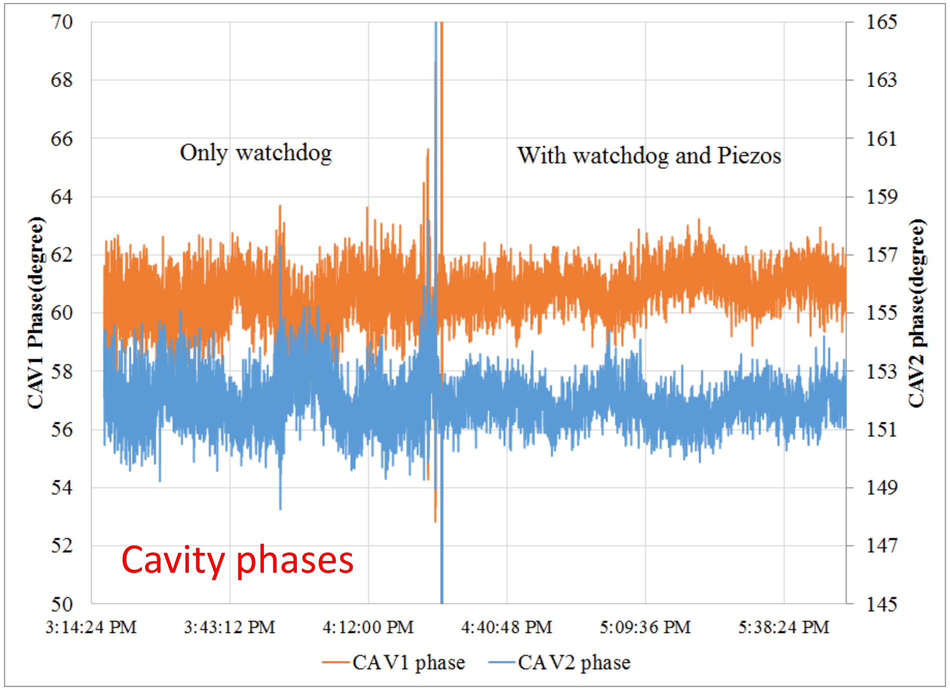
Added Piezos to each tuner stack and use tuner loop phase error signals to drive Piezos

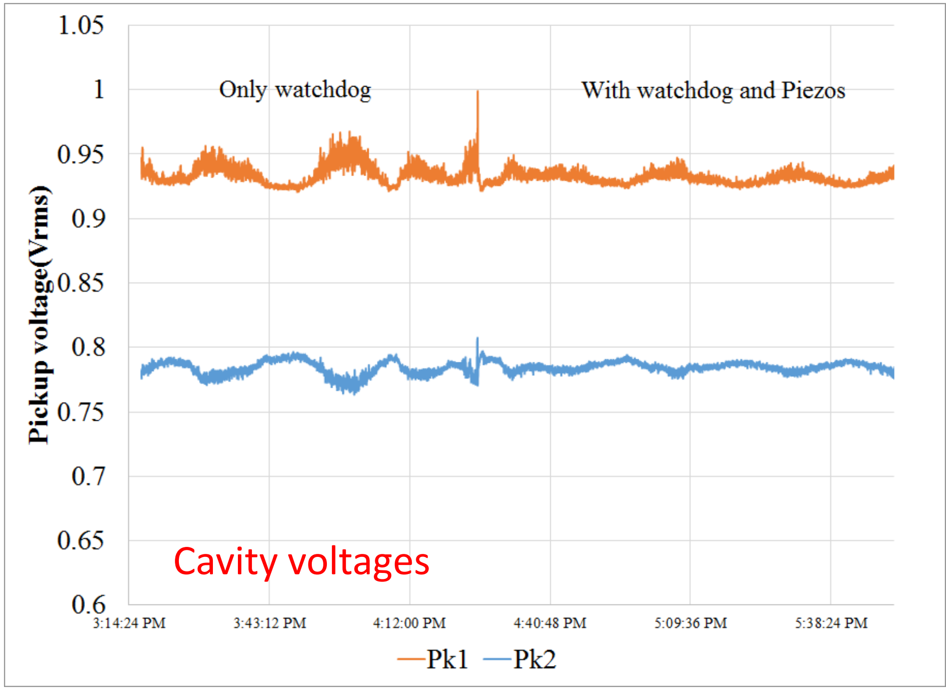
ACM1 Piezo operation

- A piezo was added to each tuner stack in ACM1
- Driven with the LLRF tuner signal after applying band pass filter and proper phase shift
- Suppresses 35Hz microphonics peak in each cavity by a factor of 4
- Small increase in 21 Hz and 130Hz peaks





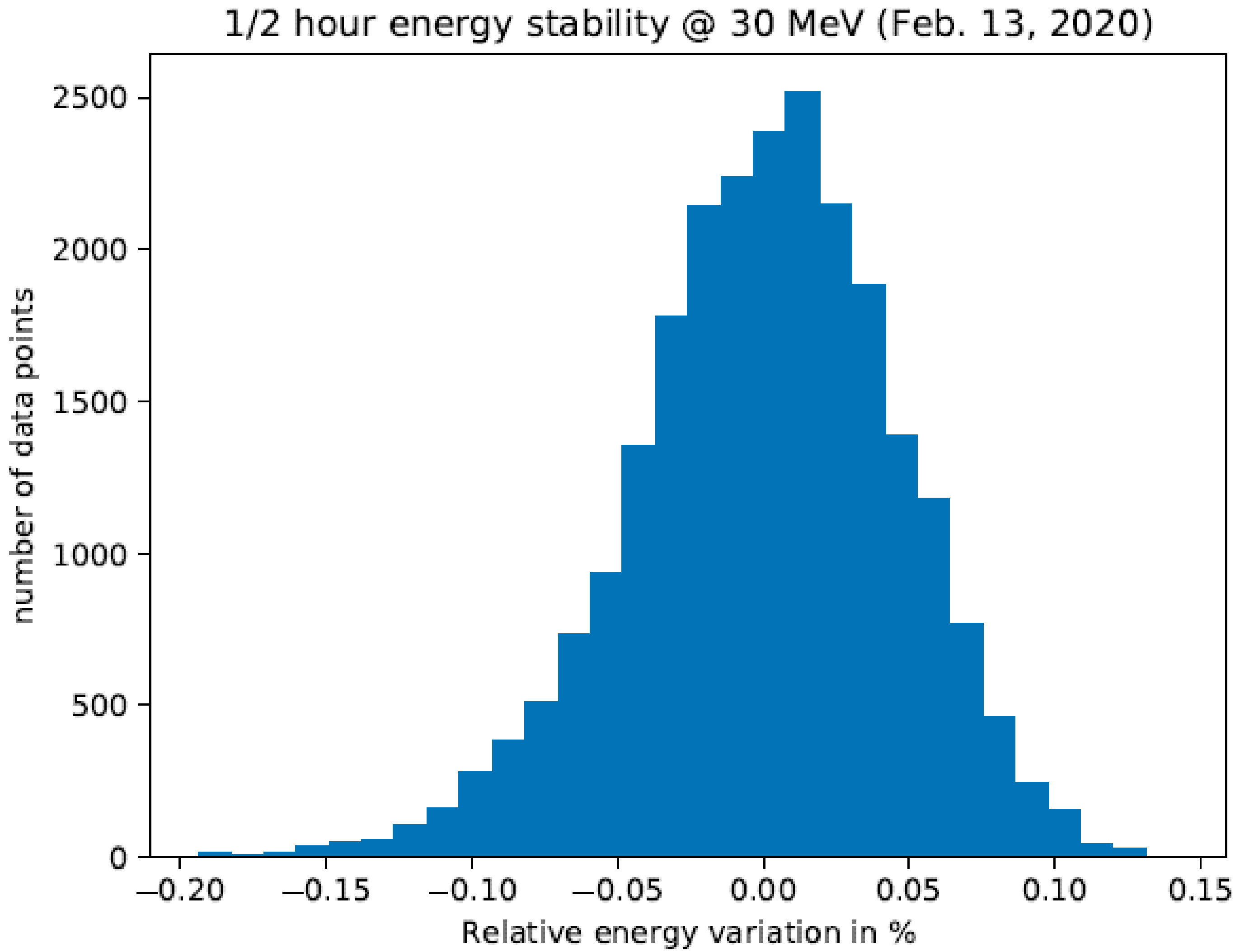




With Piezos ACM1 is more stable

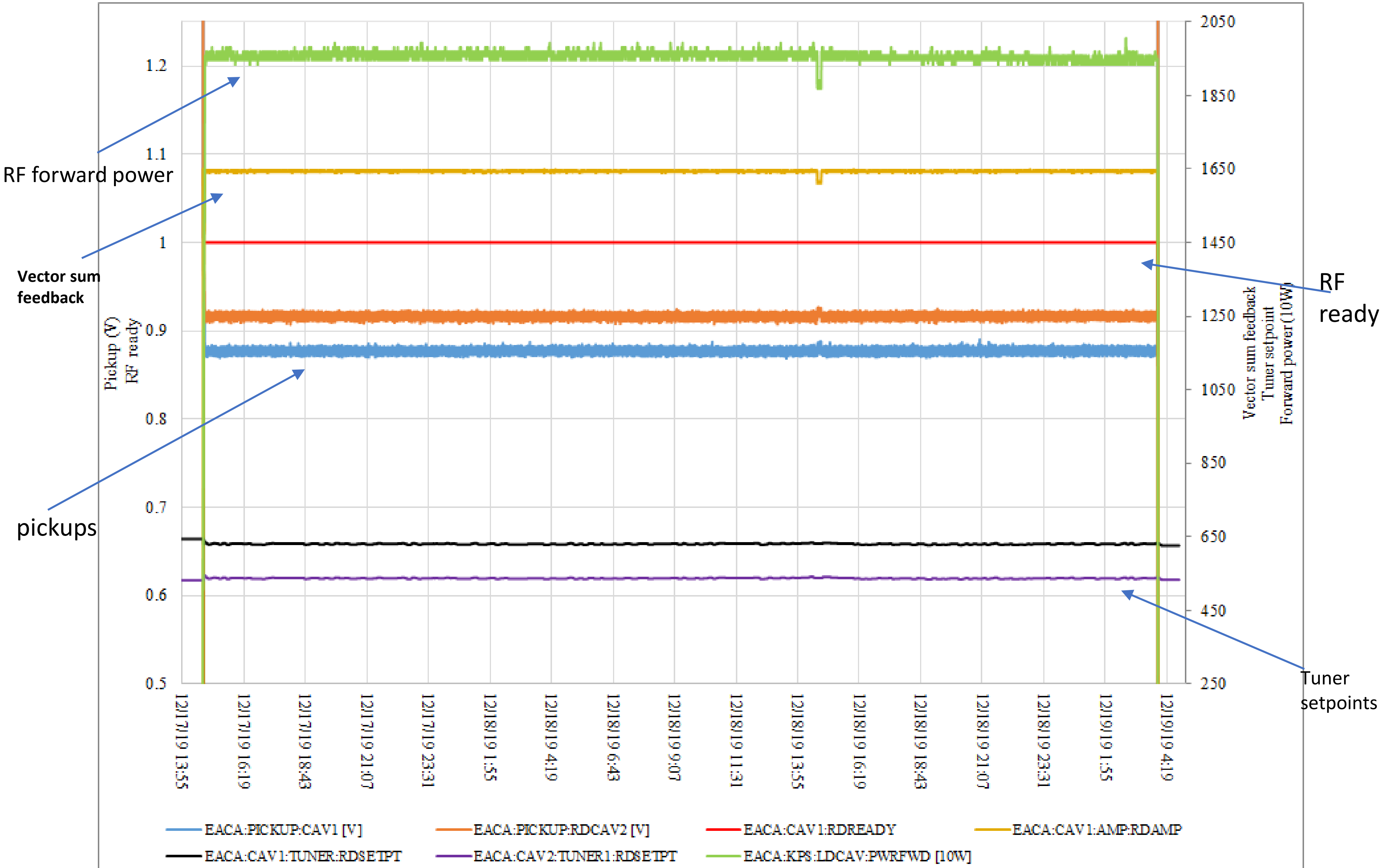
	Only watchdog		Piezo cav1		Piezo Cav1&2	
	Amplitude variation (rms-%)	Phase variation (rms-deg)	Amplitude variation (rms-%)	Phase variation (rms-deg)	Amplitude variation (rms-%)	Phase variation (rms-deg)
ACM1-Cav1	0.87	0.99	0.46	0.76	0.47	0.65
ACM1-Cav2	0.79	0.97	0.65	0.79	0.39	0.62
ACM1 V-sum	0.057				0.04	

Beam energy Stability



Relative fluctuation of the beam energy measured at a dispersive location over a period of time of > 30 min. FWHM= 0.09%.

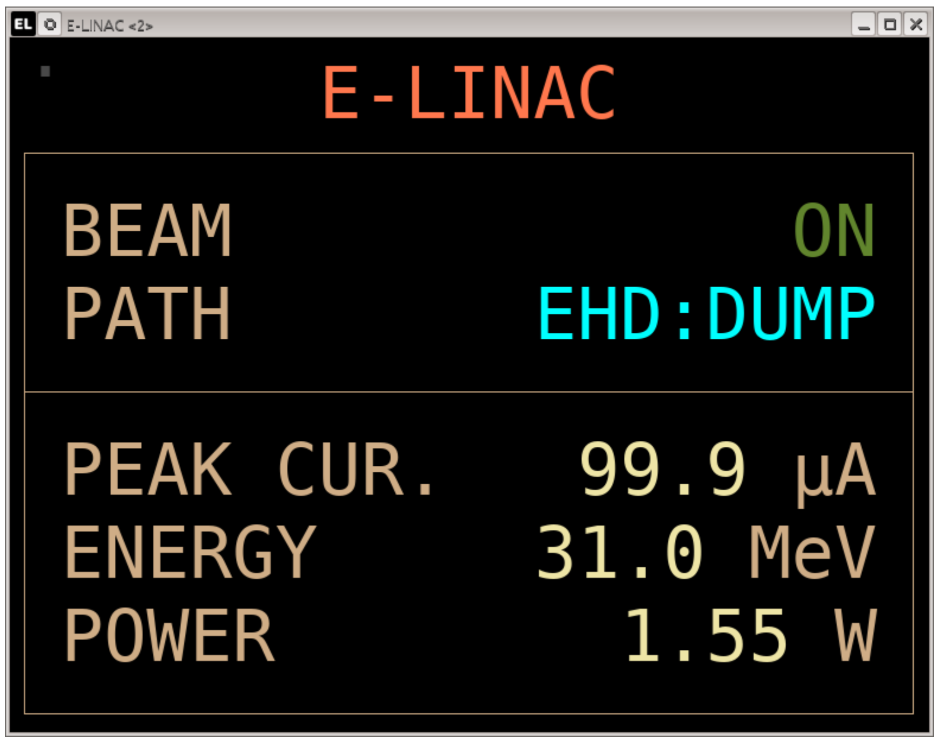
RF stability demonstration



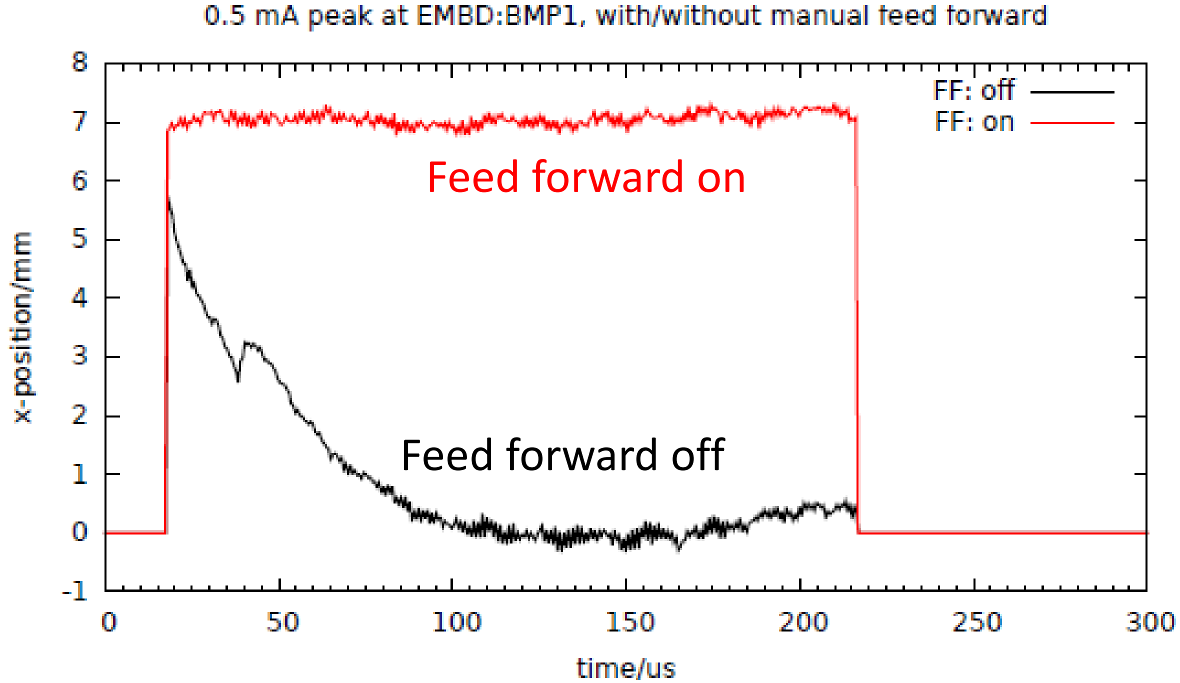
37 hours of uninterrupted operation of ACM1 at 20MV vector sum

31MeV Beam to Dump

- ICM---8.5MeV
- ACM1---22.5MeV
- ICM1 limited by strong x-ray and ACM1 JT valve fully open



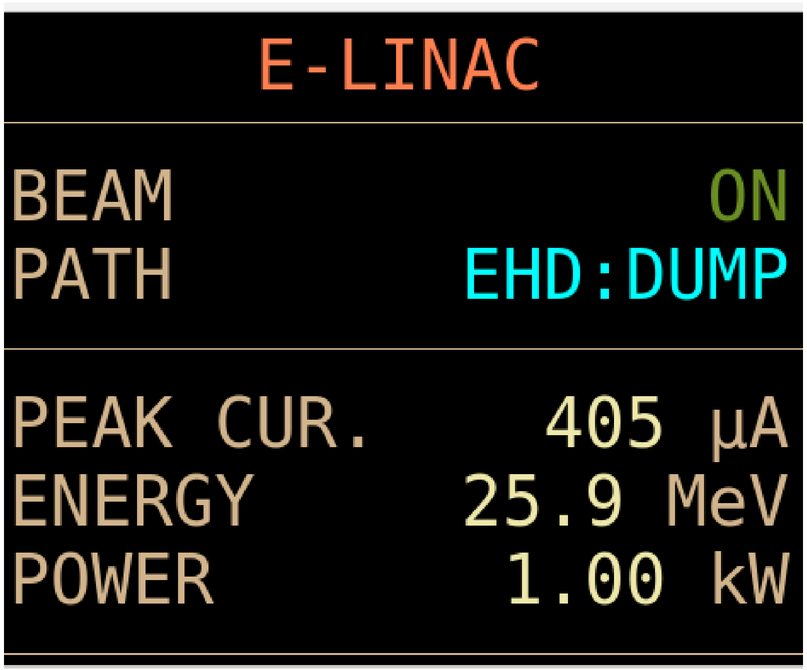
Beam Loading Compensation of ICM

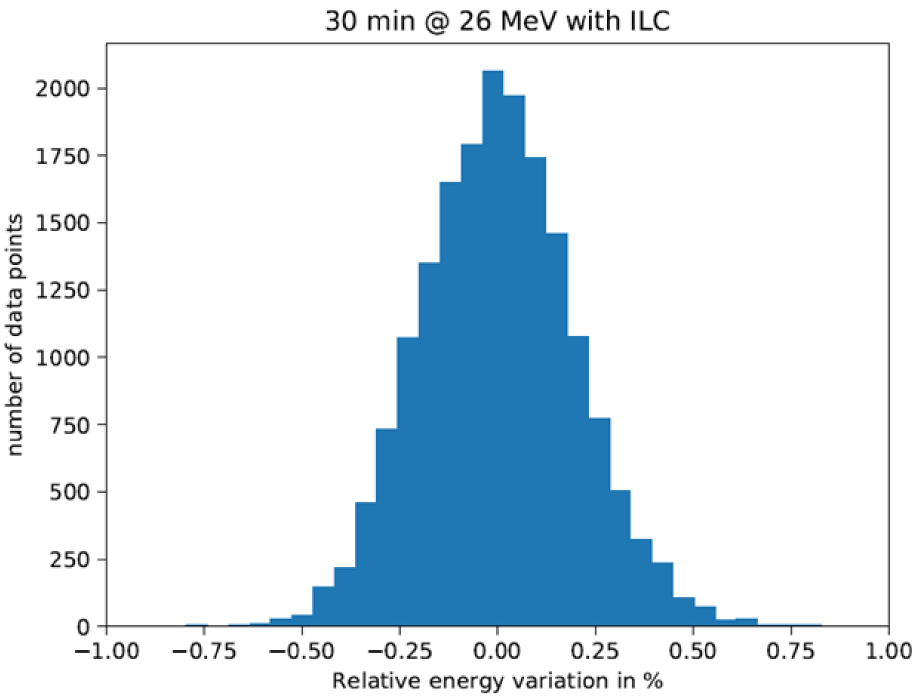


Beam centroid position along a 200 μs long pulse measured at a dispersive location downstream of the injector cavity (@ 7 MeV).

1kW Beam to 26MeV with Feed Forward

- ICM is 7MeV + ACM1 19MeV
- 100 Hz pulse beam, 1kW average power, 1ms pulse
- Feed forward compensation
  - Adaptive feed forward compensation
  - Loading corresponds to a 16% cavity voltage droop across the pulse
  - The beam energy stability is 0.4%





Discussion

- Cavity gradients in e-Linac
  - 31MeV beam energy is achieved
  - ICM gradient is limited by strong field emission
    - ICM will be refurbished this winter
    - Setting-up a permanent venting/pumping system to mitigate further degradation
- Beam energy stability of 0.1% (RMS) achieved
  - Watchdog is added to LLRF to maintain stable tuning regime of vector sum
  - Piezo controllers are added to reduce main microphonics peak in each ACM1 cavity by a factor of 4
  - Demonstrated 37 hours of stable operation at 20MV in vector sum (ACM1)
  - 1KW beam was delivered to final beam dump in pulse mode
  - Adaptive feed forward compensation demonstrated for a loading of 16% for one hour with a beam energy stability of 0.4%
- Road map for beam power
  - 10kW in 2021
  - 10kW reliability and operator training in 2022
  - 100kW in 2024

Thank you!
Merci!

Questions?

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