Main Linac Cryomodule and LLRF

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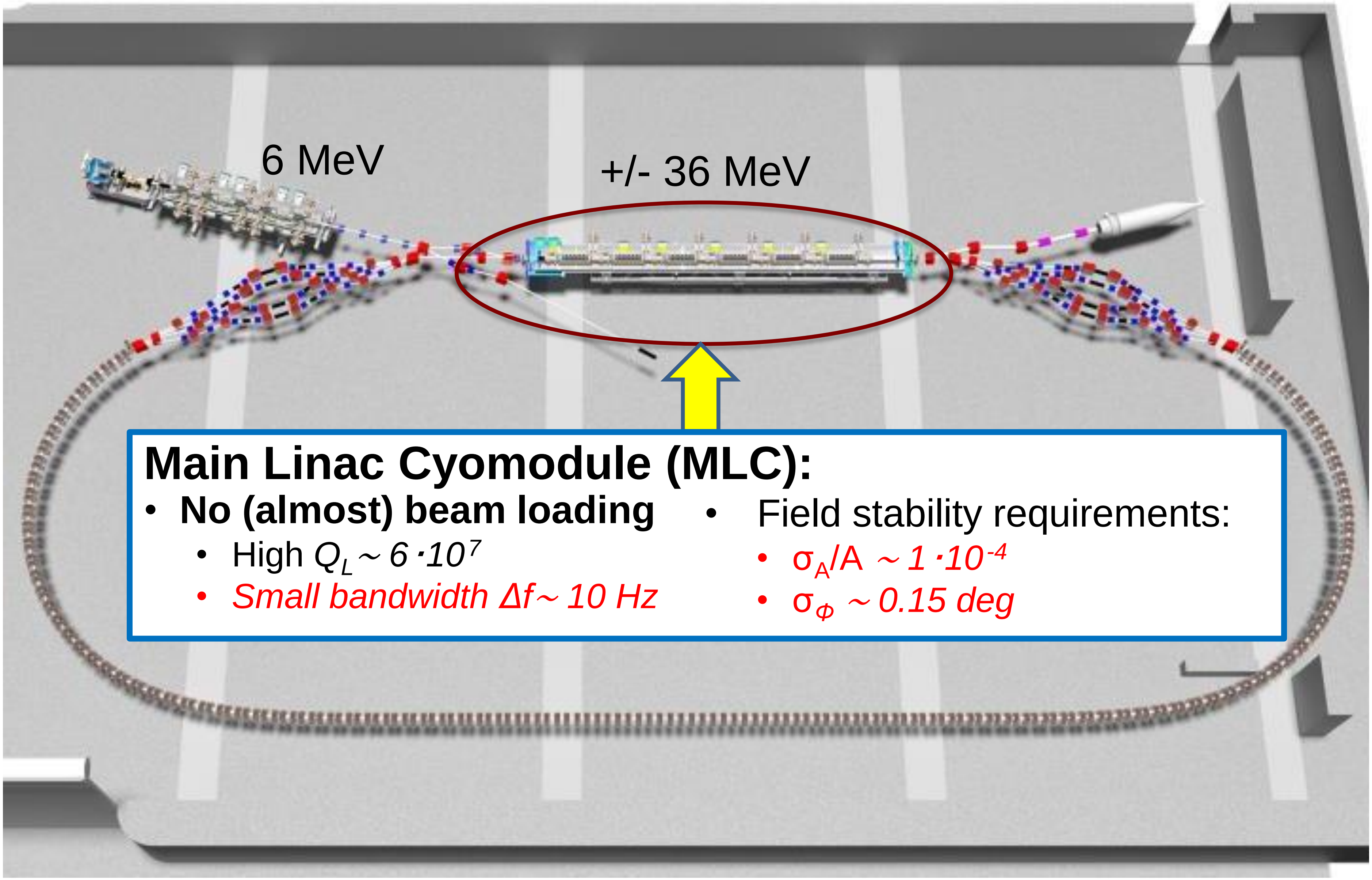
Outline

- Introduction
- MLC status
- MLC LLRF
- Next steps

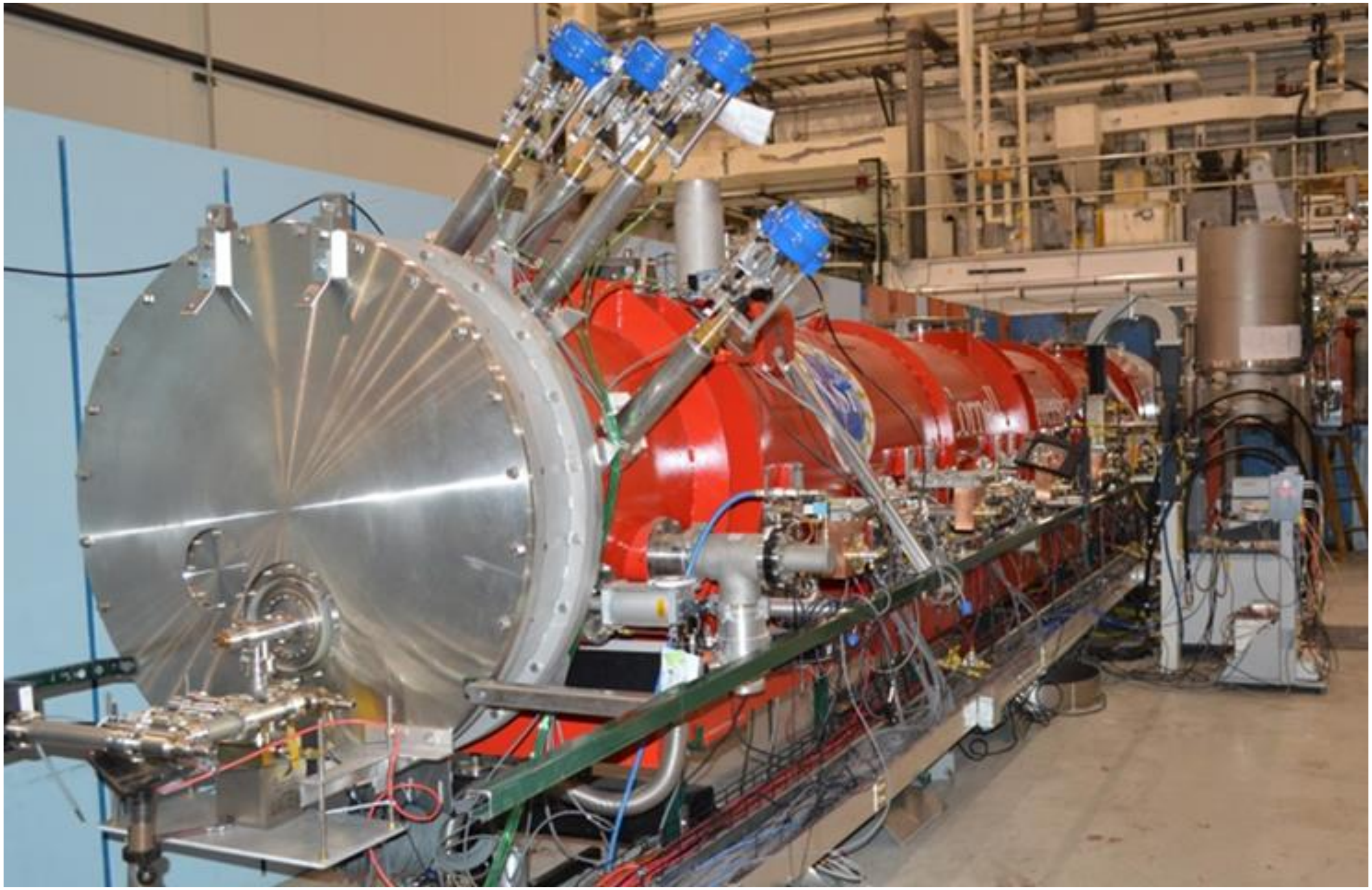
Introduction



Main Linac Cyomodule (MLC):

- **No (almost) beam loading**
  - High $Q_L \sim 6 \cdot 10^7$
  - *Small bandwidth $\Delta f \sim 10$ Hz*
- Field stability requirements:
  - $\sigma_A/A \sim 1 \cdot 10^{-4}$
  - $\sigma_\Phi \sim 0.15$ deg

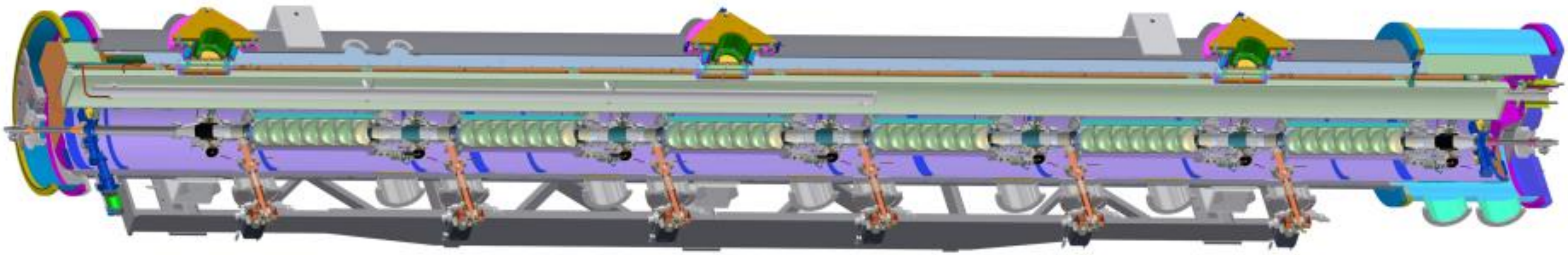
Main Linac Cryomodule



- **Hosts six ERL Main Linac 7-cell cavities**
- **Cavity preparation: bulk BCP, 650C outgassing, final BCP, 120C bake, HF rinse**

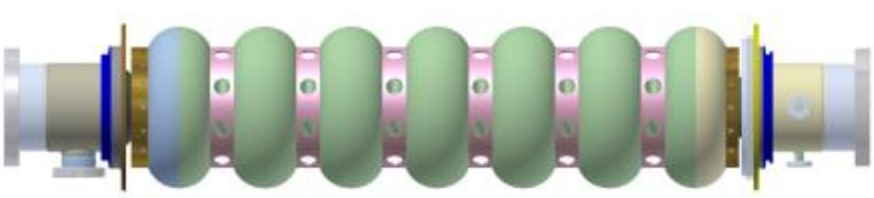
7-cell cavities and MLC parameters

CBETA

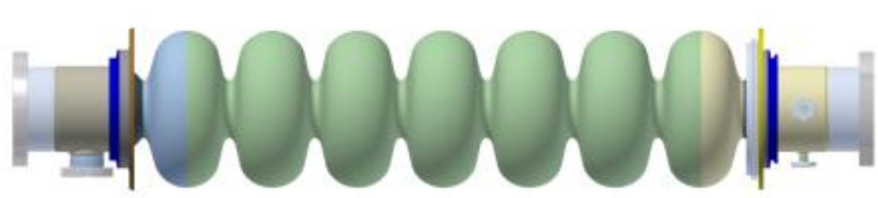


Number of 7 cell cavities	6	Number of HOM loads	7
Accelerating gradient	16.2MV/m	HOM power per cavity	200 W
R/Q (linac definition)	774 Ohm	Couplers per cavity	1
Q_{ext}	6.0×10^7	RF power per cavity	10 kW max
Total 2K/5K/8K loads	76 W / 70 W / 150 W	Amplitude/phase stability	10^{-4} / 0.05° (rms)
		Module length	9.8 m

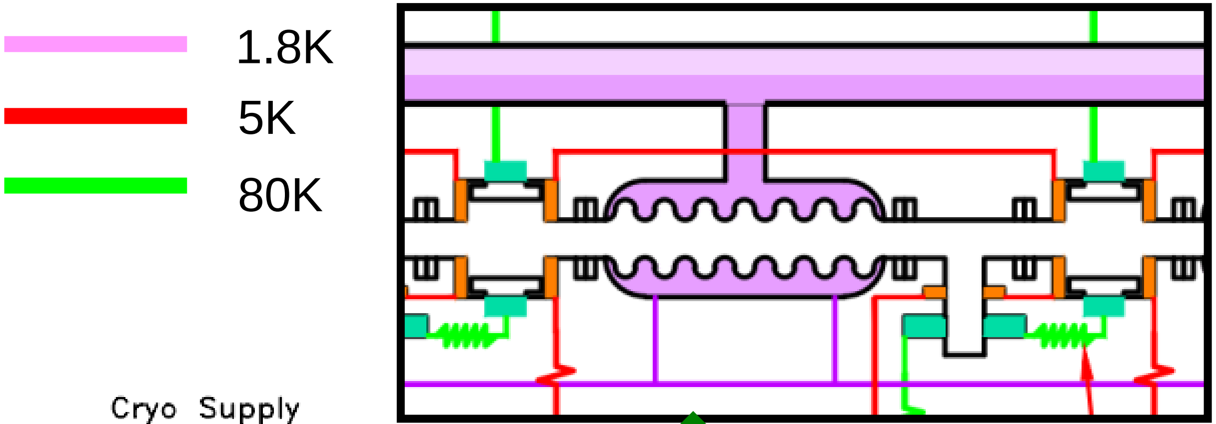
Stiffened Cavity

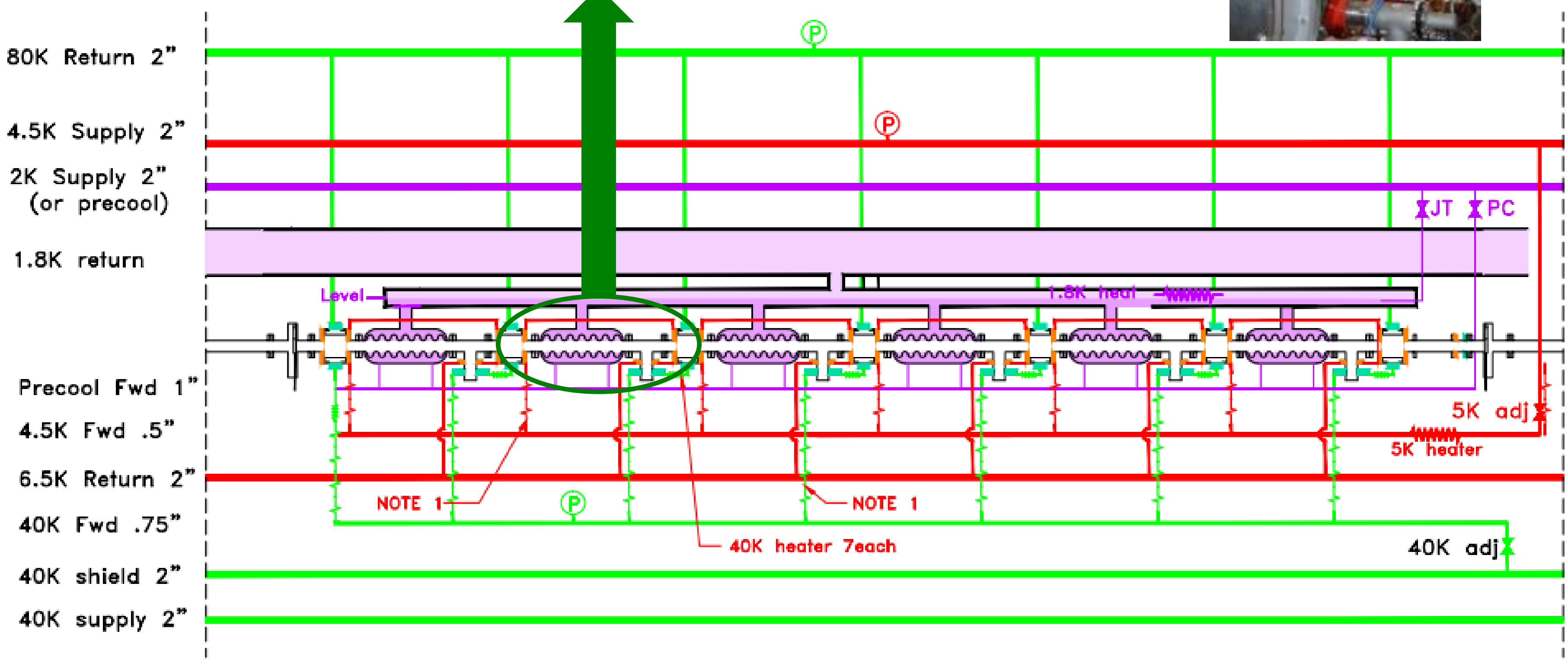


Un-stiffened Cavity

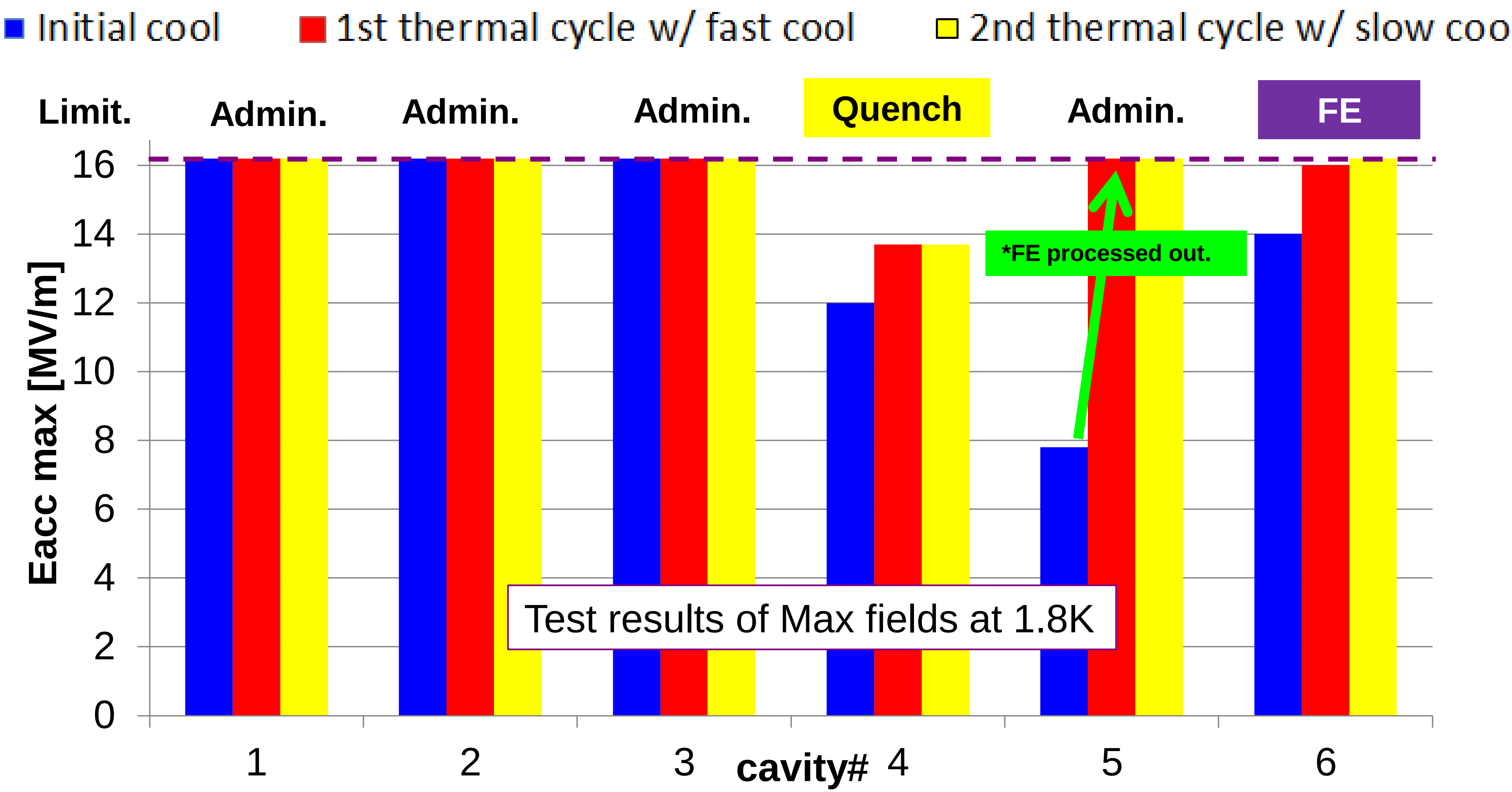


Prototype MLC Cooling schematic



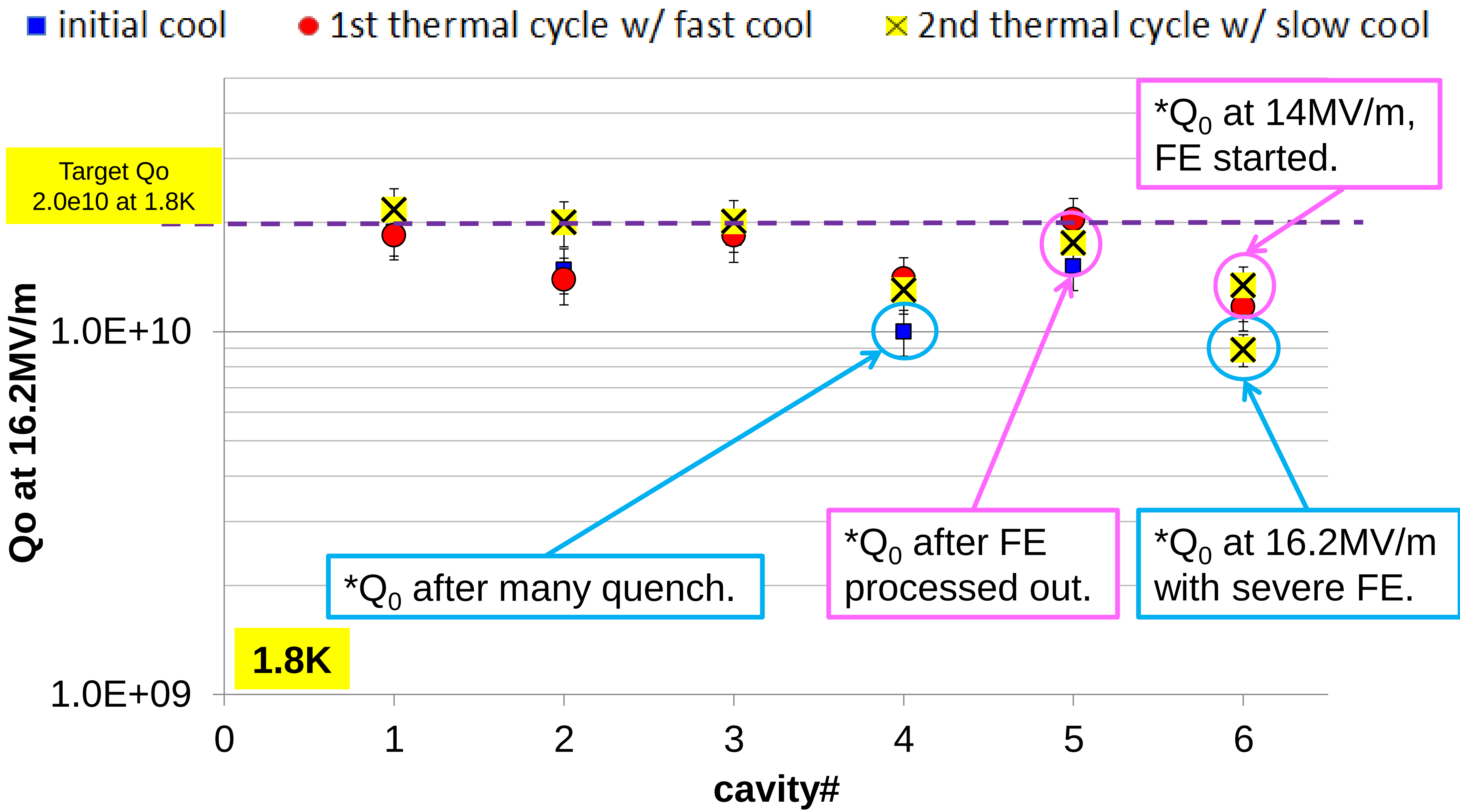


MLC cavity RF test at 1.8K



- 5 of 6 cavities had achieved MLC design gradient of 16.2MV/m at 1.8K in MLC.
- Cavity#4 is limited by quench so far, no detectable radiation during test.
- **Enough Voltage for 76MeV per ERL turn.**

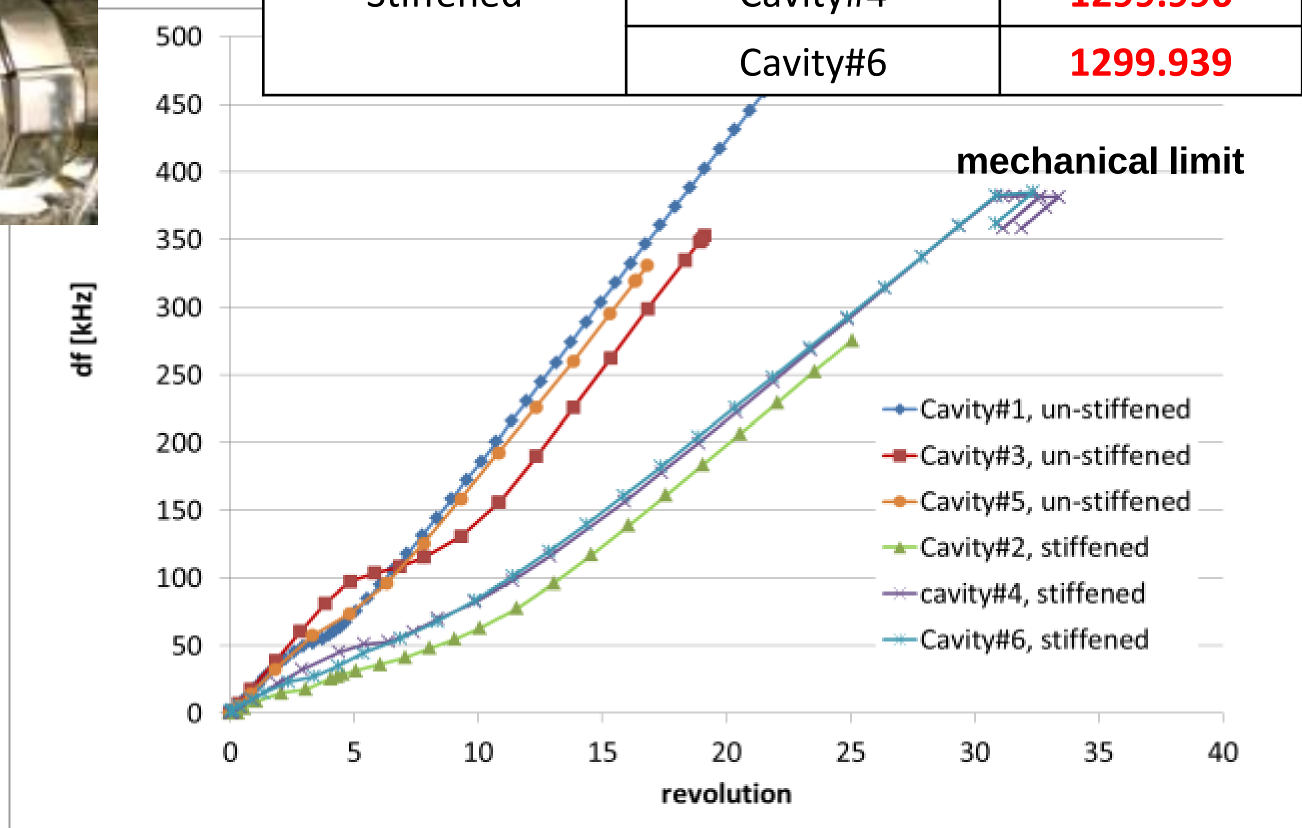
MLC cavity Q_0 at 16.2MV/m, 1.8K



- 4 of 6 cavities had achieved design Q_0 of 2.0E+10 at 1.8K.
- **Enough cooling for 73MeV per ERL turn.**

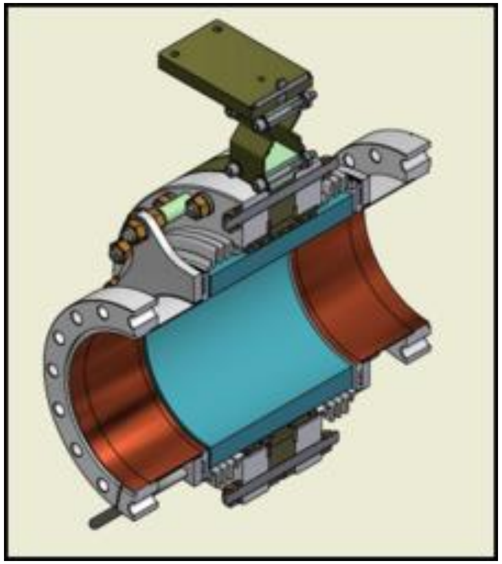
MLC slow tuner test

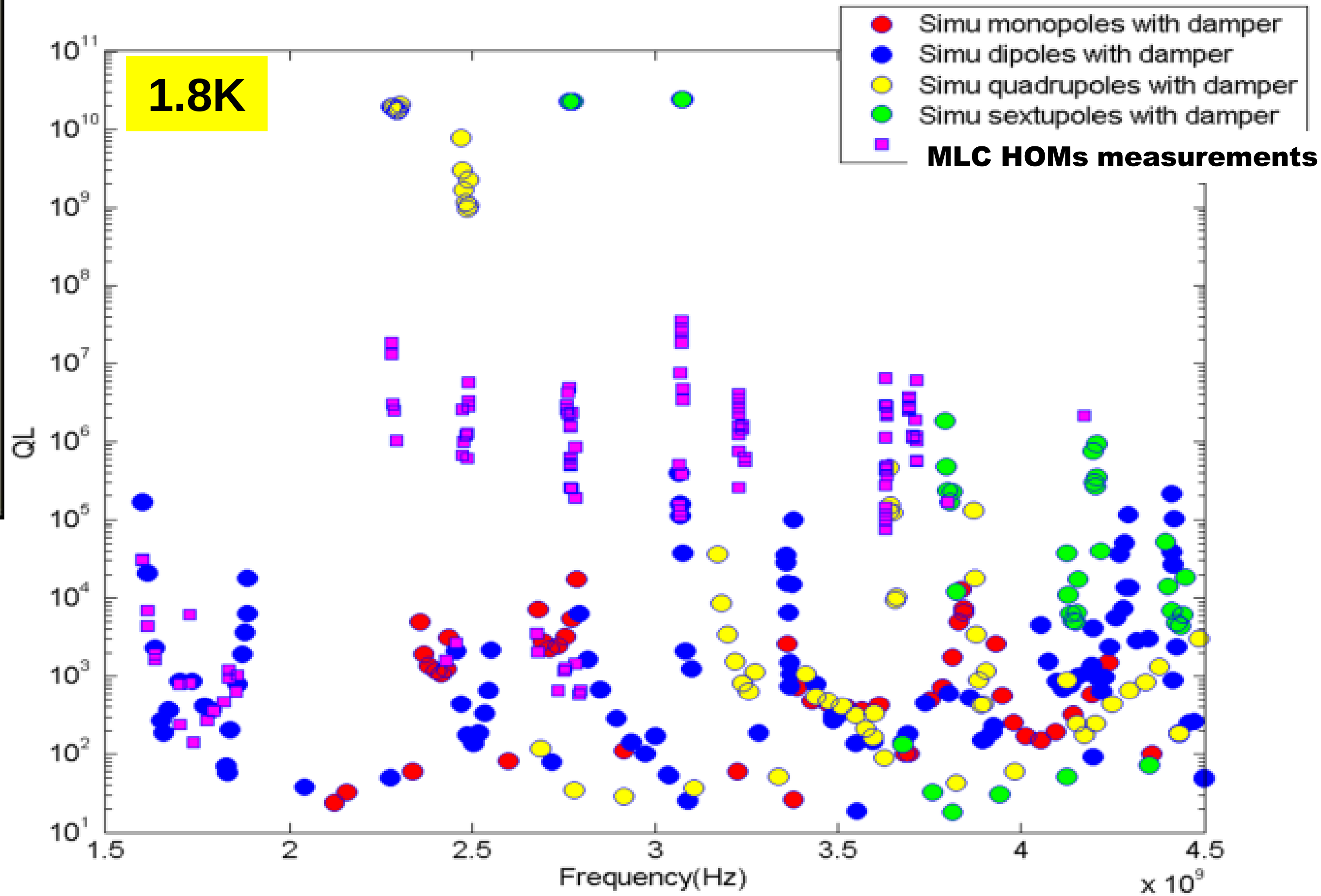
Frequency, post tuned at 1.8K [MHz]		
Design		1300.0000
Un-stiffened	Cavity#1, #3, #5	1300.000
Stiffened	Cavity#2	1300.000
	Cavity#4	1299.996
	Cavity#6	1299.939



CBETA will have to run somewhat below 1.3GHz since some of the MLC cavities can not be tuned that far.

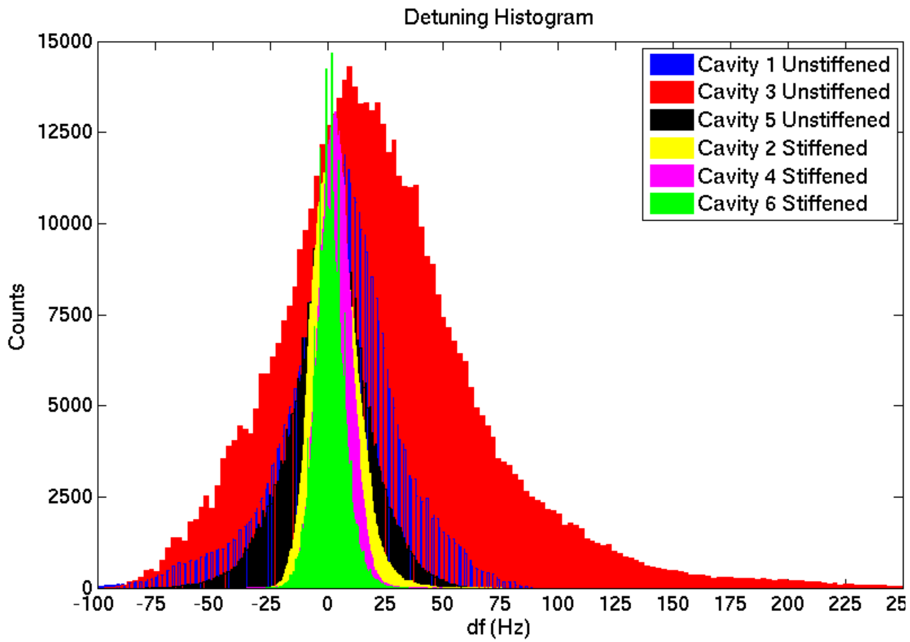
HOM scan analysis

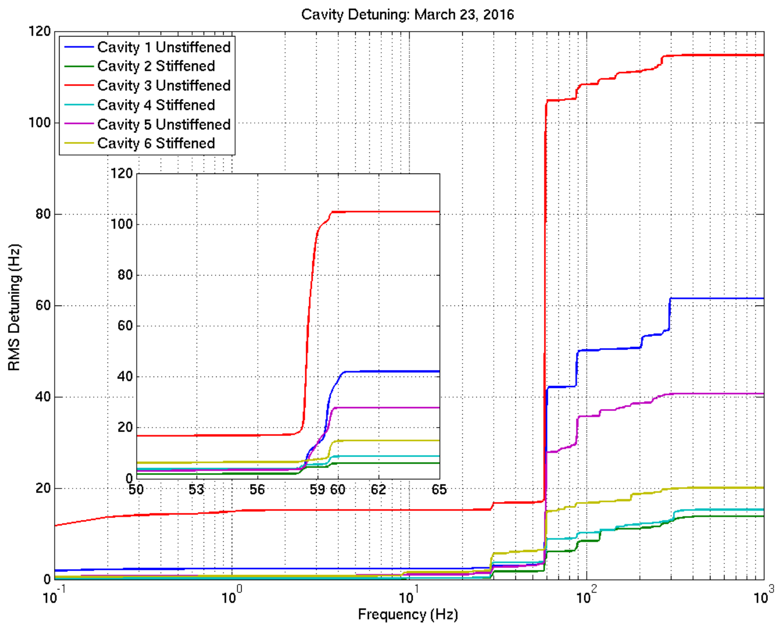




Dipole HOMs on MLC were strongly damped below Q~10^4.
Consistent with HTC and simulation results.

RF Detuning Measurements





Preliminary results:

- Average detuning of stiffened cavities: ~30Hz, un-stiffened cavities: ~150Hz.
- Integrated detuning gains dramatically at 60Hz.
- Optimization studies for the piezoelectric fast tuner compensations are in progress.

Mechanical vibration sources

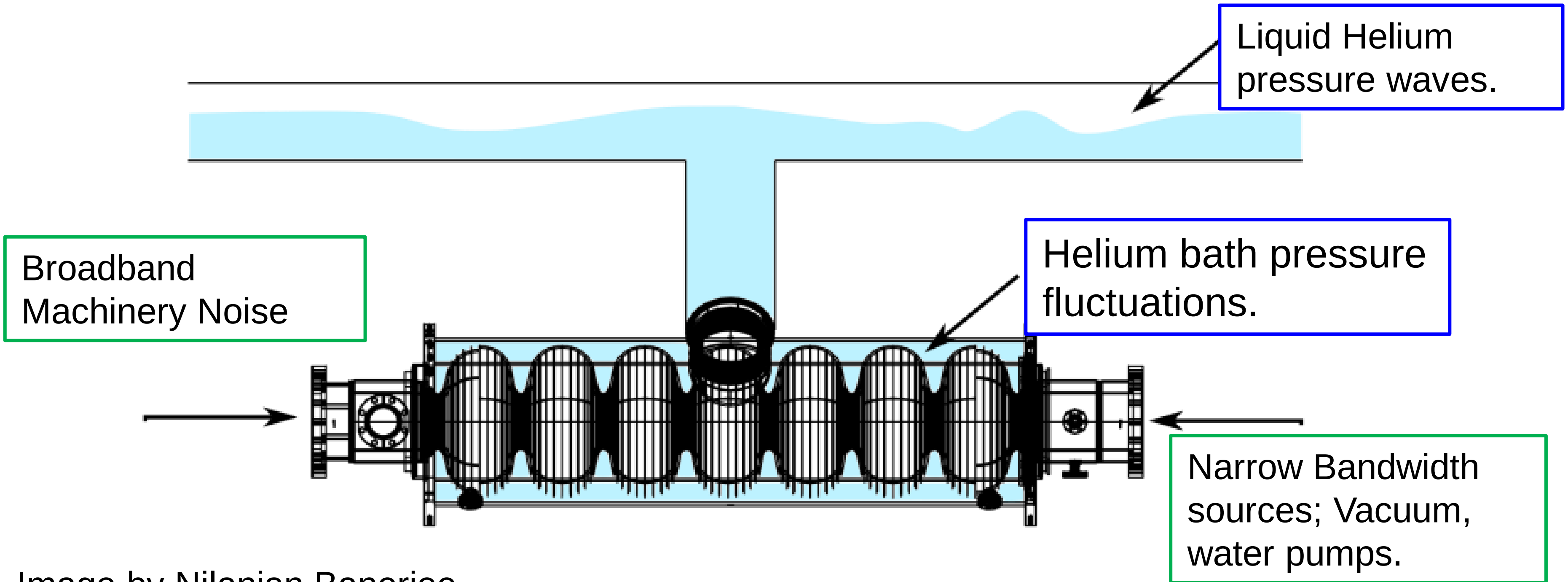
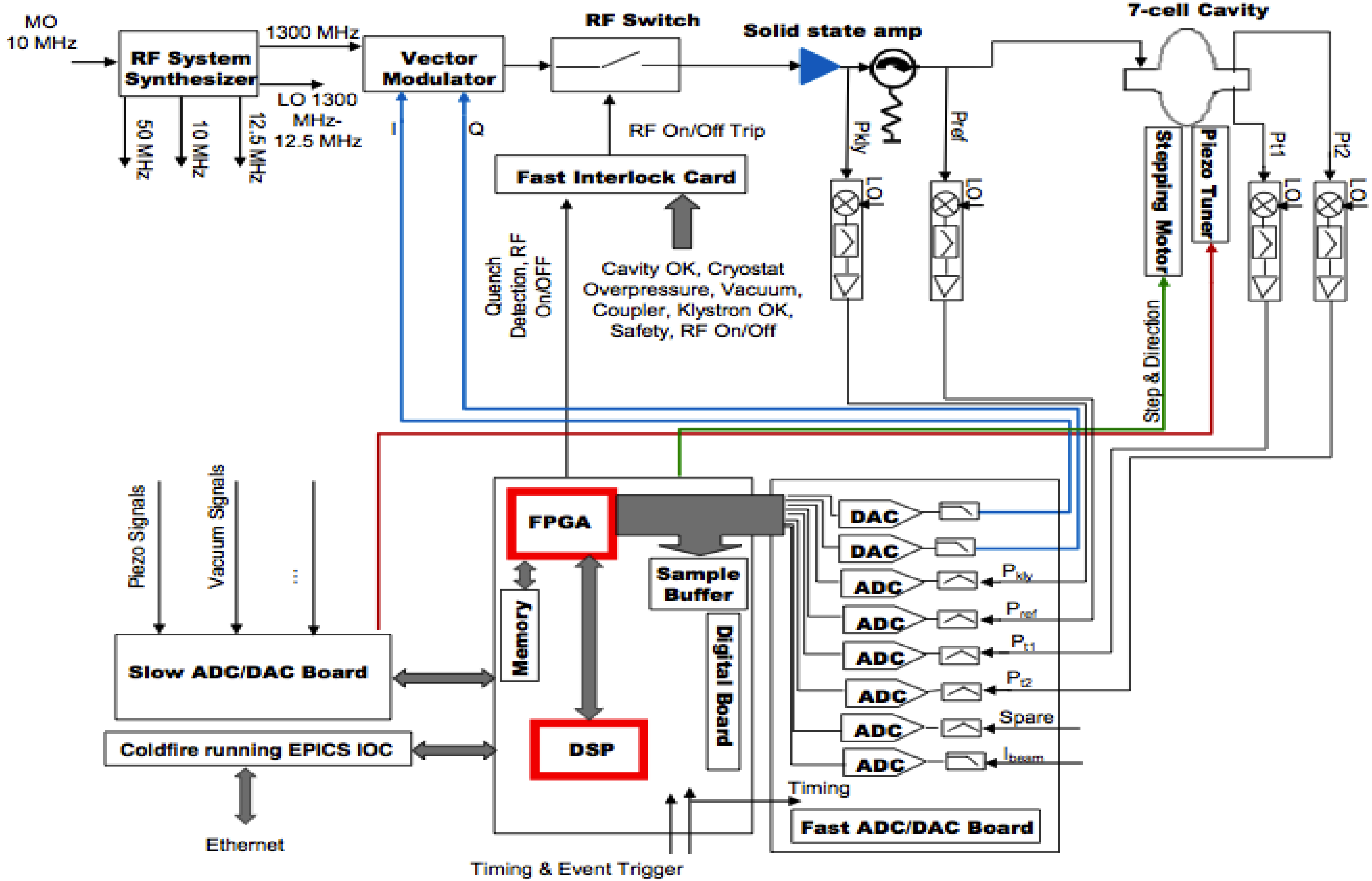


Image by Nilanjan Banerjee
(Graduate Student)

- Preliminary identification and isolation of vibration sources were done in the current MLC location.
- Further optimization on the MLC cooling scheme and compensation of microphonics with piezoelectric fast tuner are planned during the MLC commissioning in the beamline location.

Main Linac LLRF



Block diagram of the MLC LLRF system for a 7-cell cavity.

Cornell LLRF system tests

Facility	Conditions	Field stability
Requirements on CBETA	Q_L ~ $6x10^7$ (10 Hz half bandwidth)	$\sigma_A/A \sim 1x10^{-4}$ $\sigma_\Phi \sim 0.02deg$
1.5GHz ERL cavity at Jlab	Q_L up to $1.2x10^8$ (6 Hz half bandwidth) 5 mA energy recovered beam	$\sigma_A/A \sim 1x10^{-4}$ $\sigma_\Phi \sim 0.02deg$
1.3GHz 9-cell cavity at HoBiCaT at HZB	Q_L up to $2x10^8$ (3 Hz bandwidth) Peak microphonics: ~ 30 Hz)	$\sigma_A/A < 1x10^{-4}$ $\sigma_\Phi \sim 0.01deg$
1.3GHz 7-cell cavity at HTC* at Cornell	Q_L ~ $5x10^7$ (13 Hz half bandwidth) Peak microphonics: ~40 Hz 5 kW solid state RF amp	$\sigma_A/A \sim 6.5x10^{-5}$ $\sigma_\Phi \sim 0.01$ deg

***Cornell Horizontal Test Cryomodule**

- Cornell digital LLRF system for CBETA tested extensively with a wide range of parameters. Field stability meets and exceeds CBETA specifications. All digital components and control codes on hand.
- microphonics in some of the MLC cavities might be quite large (if we can't find ways of reducing it). That also would have some impact on the field stability achievable.
- CBETA requirements are quite tight, so **dedicated LLRF studies will be needed and are quite important.**

Solid State RF Amplifier Procurement (1)

1. The MLC requires six SSAs to:

- Establish and maintain stable accelerating field in each MLC SRF cavity (one SSA per cavity needed in high loaded Q operation).

- Sufficient RF power overhead needed to

(1) compensate significant cavity field perturbations due microphonics,
(2) compensate residual beam loading due to return phase errors and during current ramp up,
(3) for responses to beam instabilities and trips.

2. The MLC has six accelerating cavities, three "stiffened" and three "un-stiffened":

- Un-stiffened cavities are more susceptible to detuning due to microphonics. This condition requires more RF power to maintain RF field regulation.

- Stiffened cavities are less susceptible to detuning cause by microphonics. This condition requires less RF power to maintain RF field regulation.

3. Each MLC cavity has a RF power input limit of 10 kW set by the maximum RF power of the RF input coupler.

4. the plan is to acquire three SSAs at 10 kW for un-stiffened cavities and three at 5 kW for stiffened cavities. This plan should be adequate to accommodate the dynamic conditions currently anticipated for operation the MLC in CBETA.

Solid State RF Amplifier Procurement (2)

5. Eleven companies were invited to submit proposals to provide the SSAs**, three companies submitted proposals**. **SigmaPhi of France was chosen** for the following reasons:

- Cornell has had **experience** with SigmaPhi providing an SSA with positive results with both performance and service when needed.
- The company provided **real performance data** showing their ability to meet CBETA requirements for RF power.
- **Recommendations from other users** that have similar equipment.
- **Delivery schedule** is in line with CBETA operational schedule,.
- **Flexibility providing two types of SSAs.**
- SigmaPhi was **the low bidder**.

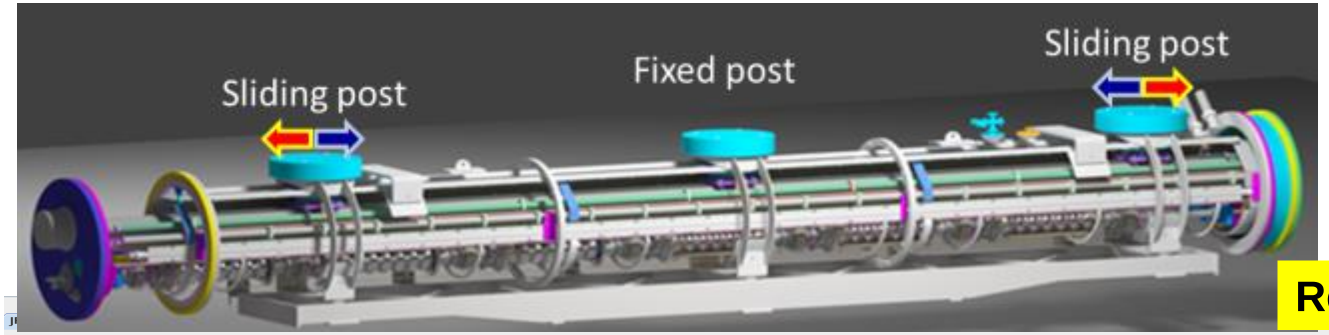
Next steps

L0E as of 2017 Jan 20th.

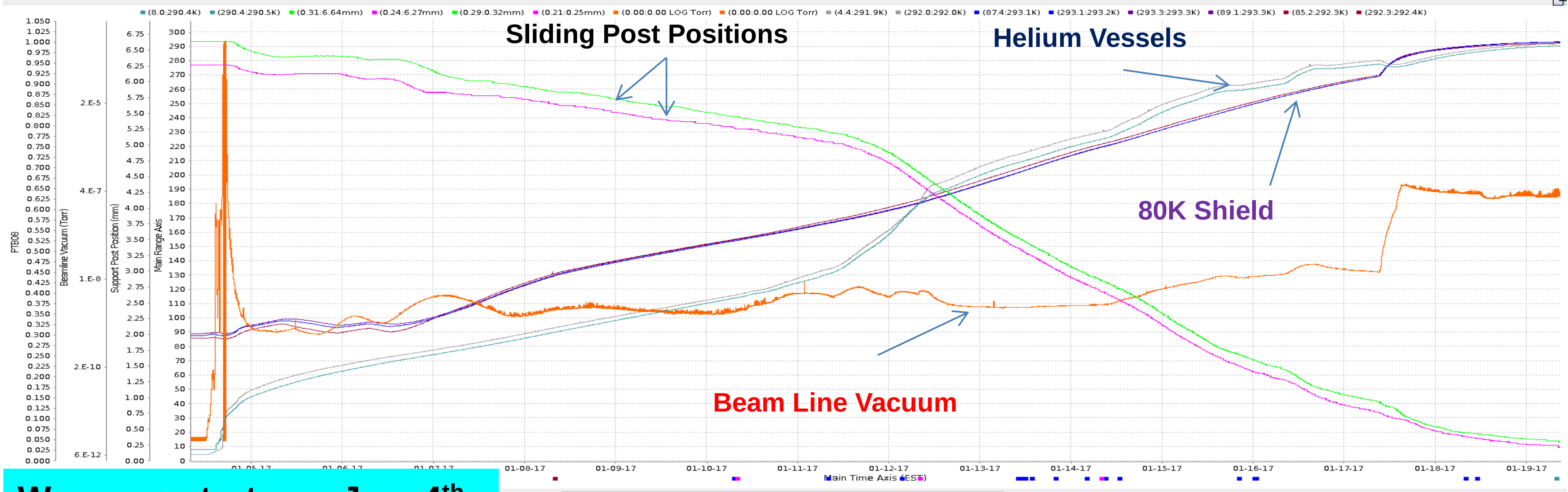
Main Linac, schedules

2017	Items
January	✓Warm-up to room temp Preparations for moving MLC
February	Move MLC to beamline location. (Wed. 1 Feb. 2017)
March	Preparations for cooldown and testing-commissioning.
April	Cooldown
May	MLC testing-commissioning
June	Beam through MLC into beam-stop
July	Water shutdown in Wilson

MLC warmed up, 4K to Room Temp.



Reached ~292K on Jan. 19th.

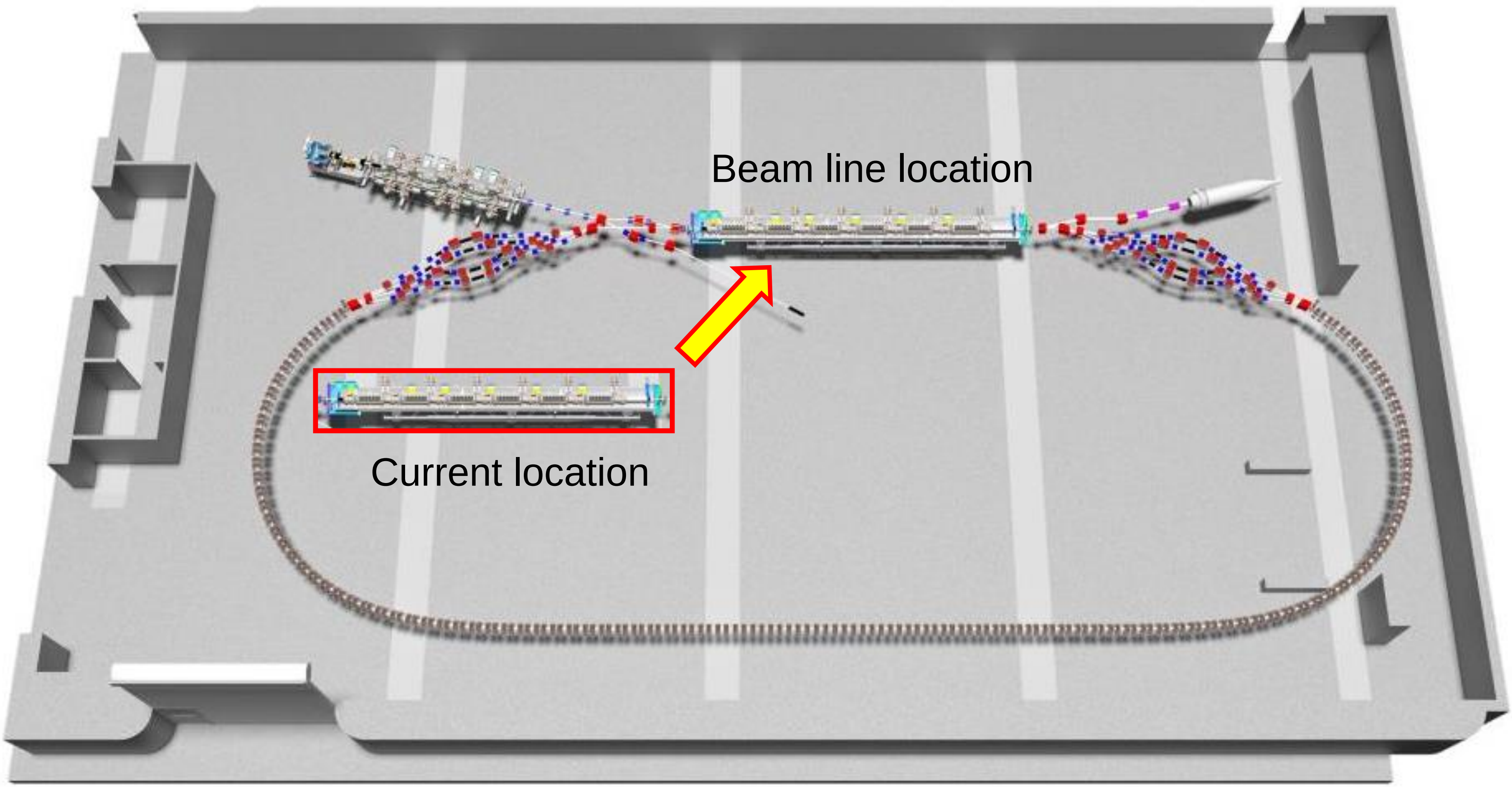


Warm-up starts on Jan. 4th.

by Peter Quigley

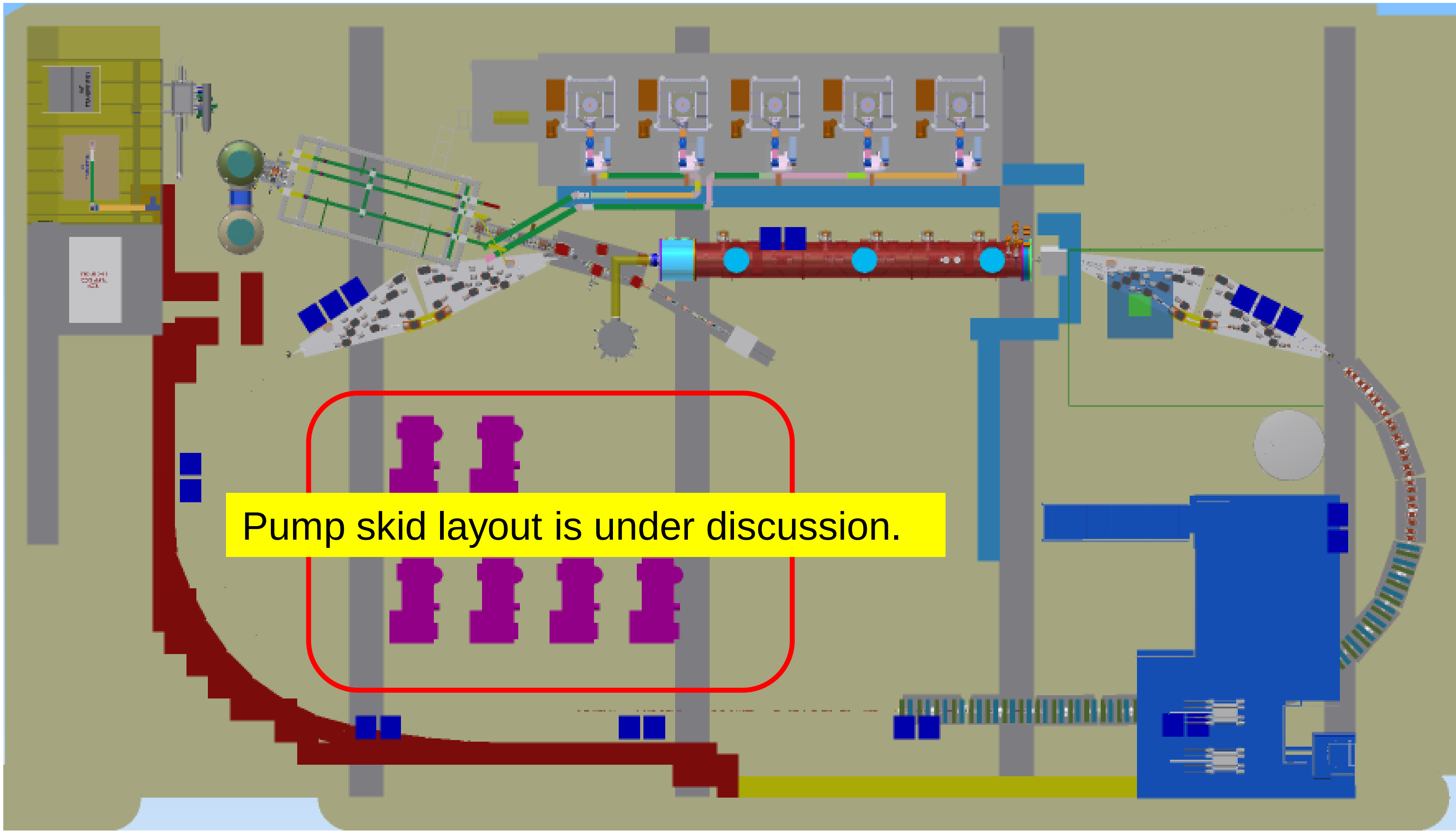
19 January 2017, 10:30 AM
MLC Currently at Room Temperature
Total string growth: ~12 mm (east 6 mm, west 6 mm), Overall Growth rate ~20 μ/hr
Overall warmup rate: ~1.0K/hr on the Helium Vessels, ~0.7 K/hr on 80K shield.

Move MLC to beamline location



Planed on February 1st

Cryogenics



Summary

- Main Linac Cryomodule is commissioned, tested, and ready for CBETA.
- Main Linac SRF LLRF; most hardware existing and concept/performance fully tested.
- Some studies and optimization remain for the MLC LLRF and microphonics.
- **Priorities**
  1. Moving the MLC to the final location. ☺ ***The day after tomorrow!***
  2. Waveguide and LLRF cable design (concepts are completed).
  3. Moving CESR transmitter to the CLEO pit.