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CW SRF cryomodule at Cornell

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Cornell's SRF and ERL team

With contributions from

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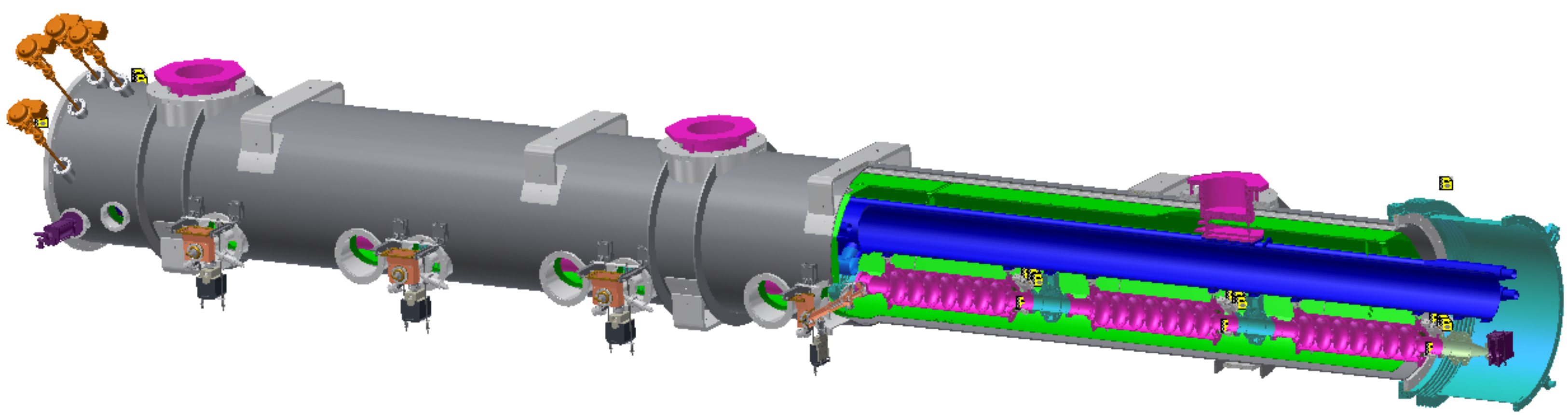
- Matthias Liepe
- Bruce Dunham



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CM Results from Cornell

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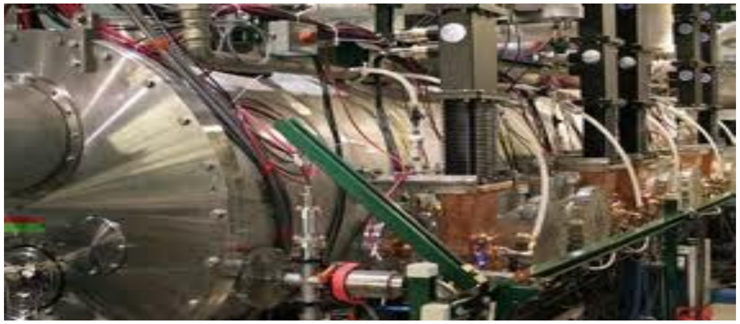
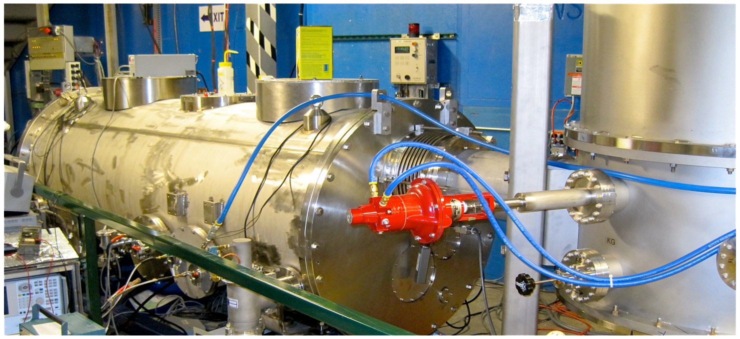
World Record CW beam current & brightness from a photoinjector



4 MeV, 75 mA CW beam accelerated by SRF cavities

World Record Q_0 of an SRF cavity in a cryomodule



$Q_0=1\cdot10^{11}$ at 1.6K, 16 MV/m in a cryomodule

Now a main ERL cryomodule is under construction

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Summary of HTC results

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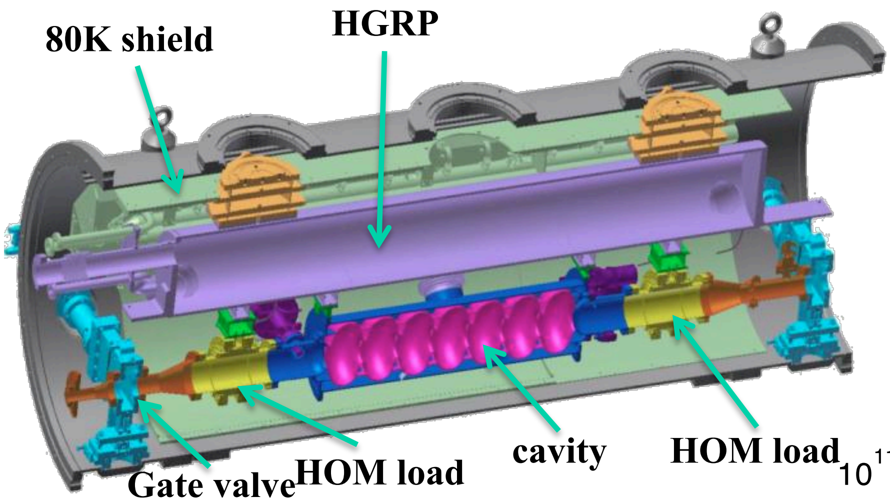

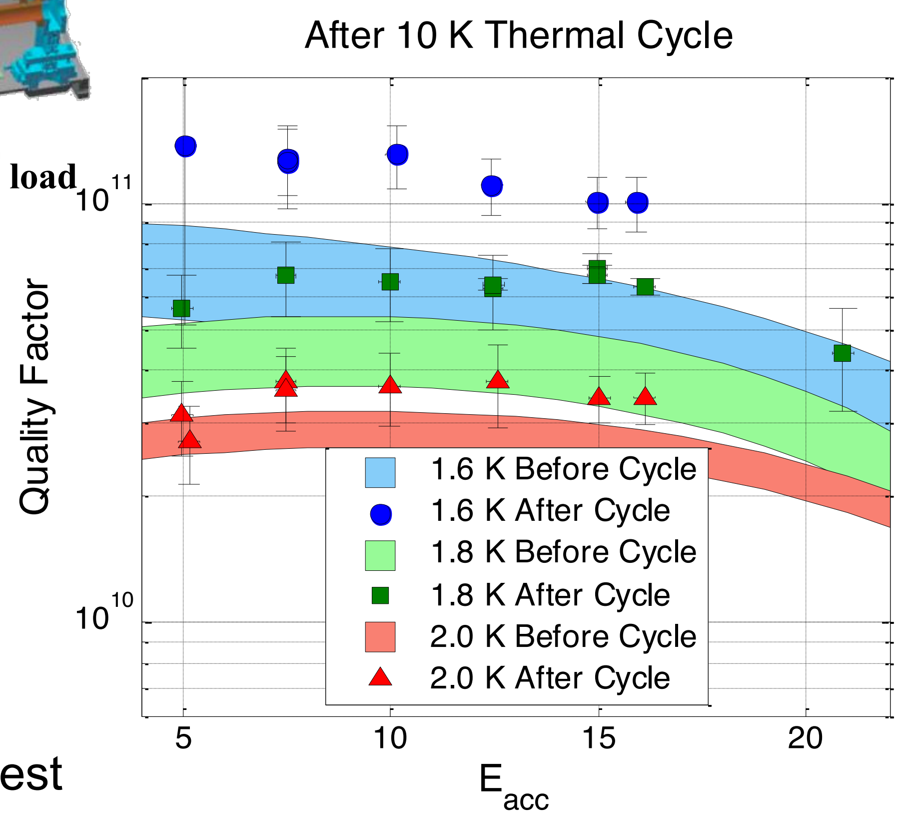

Horizontal Test Cryostat:

(@16MV/m, 1.8K):

Q0 = 3.5E10 without coupler

Q0 = 2.E10 with couplers

Q0 = 6E10 with coupler and HOM absorbers

The HTC provides the only horizontal test in an ERL-like environment

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Main ERL Cryomodule: Design and Construction

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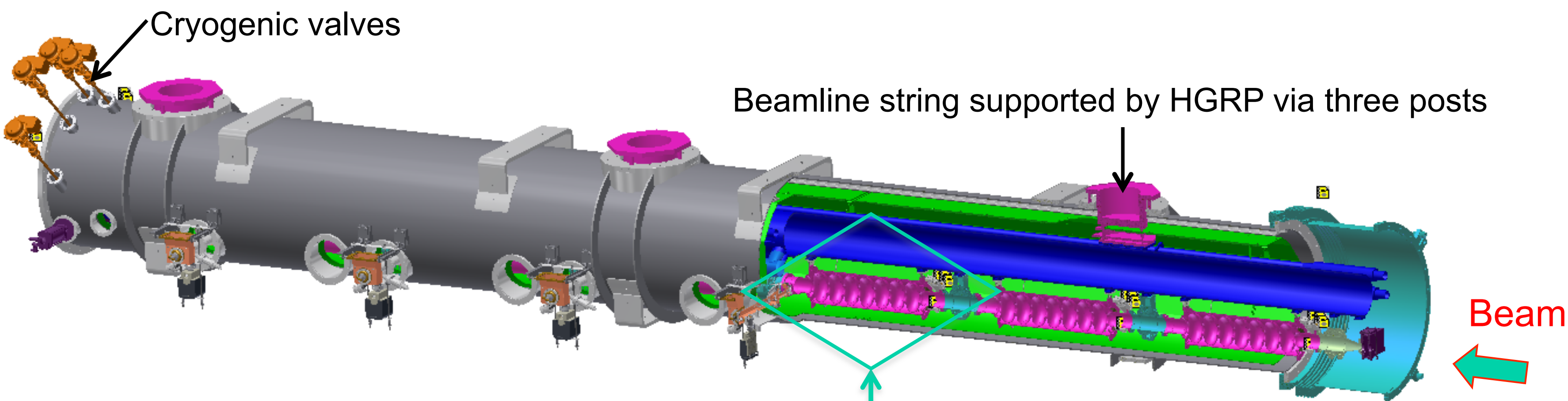
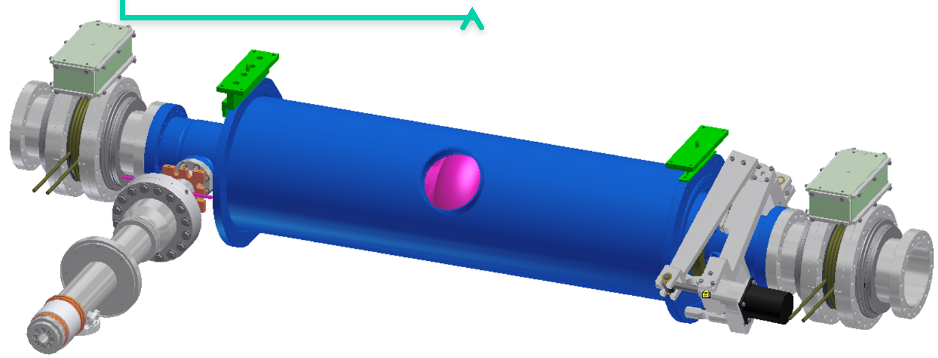


Full Cryomodule

- Modified ILC cryomodule design
- Study reproducibility of low-loss cavities
- Test cavity statistics
- Demonstrate High Q and CW operation
- Prepare industrialization of ERL linacs

Completion end of 2014



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CW Linac cryomodule for the Cornell ERL

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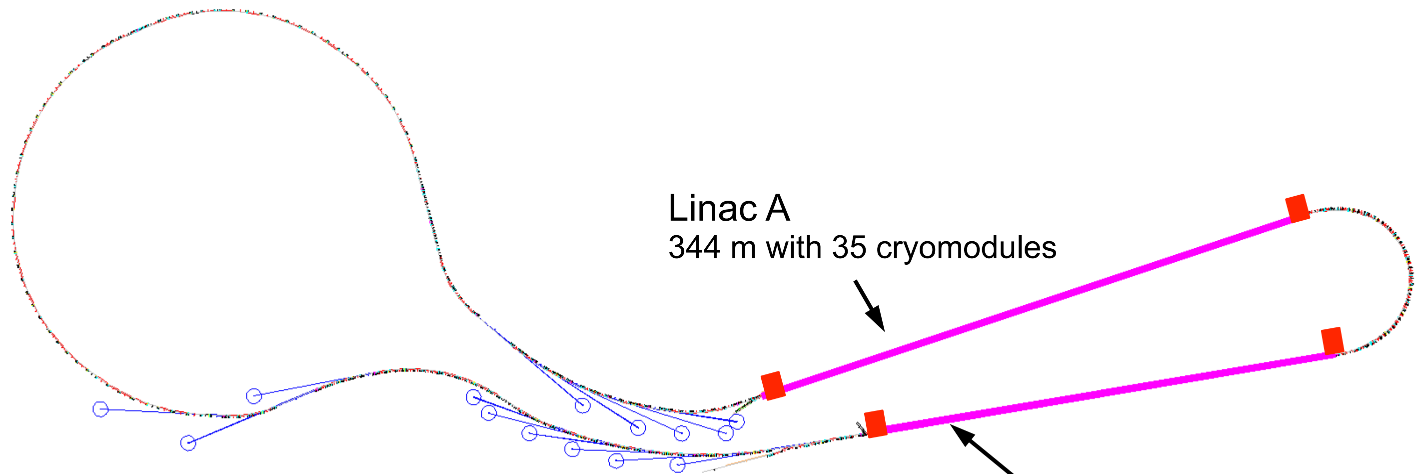
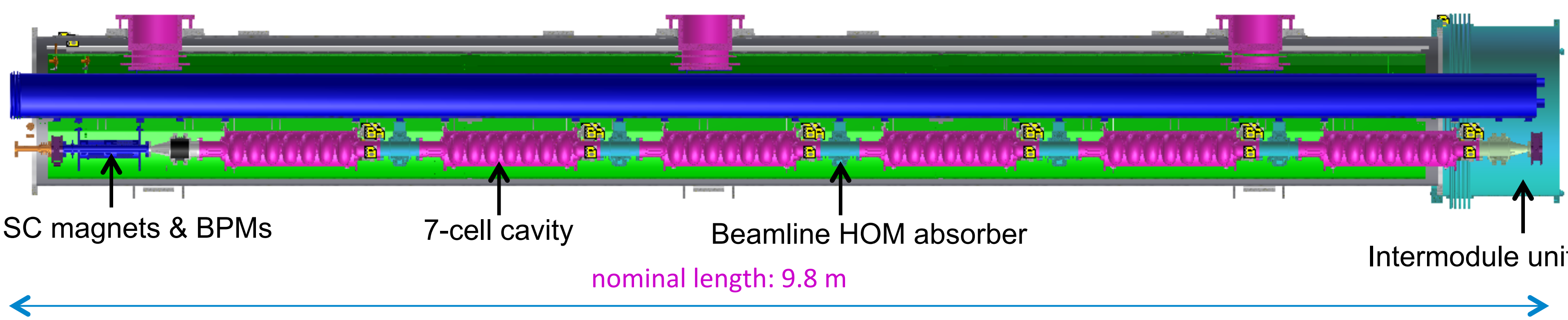


Total 64 cryomodules, each:

- six packages of 7-cell cavity/Coupler/tuner
- a SC magnets/BPMs package
- five regular HOMs/two taper HOMs



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ERL documentation: (1) Science, (2) Generic design

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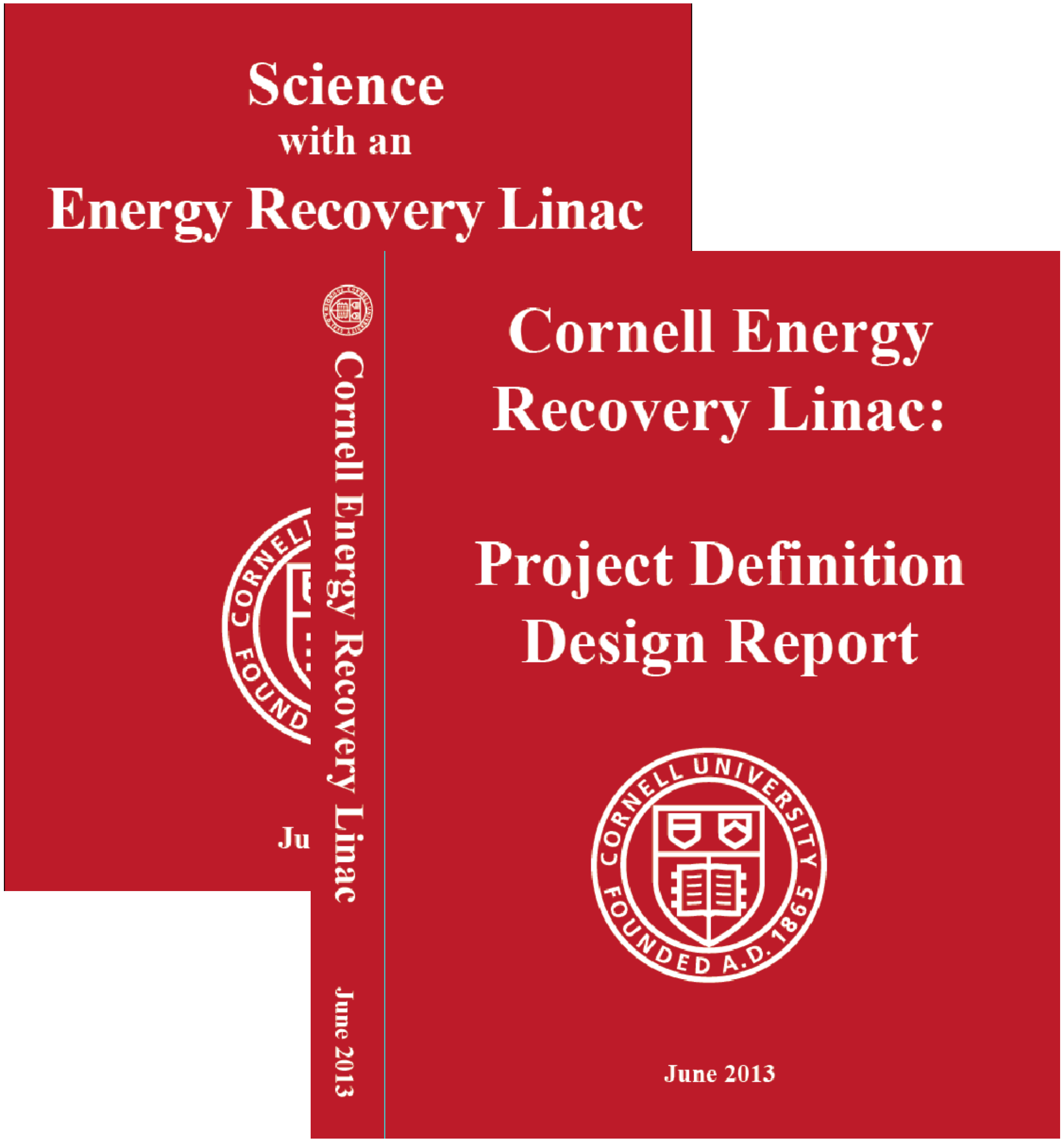

- **Science case gathered in international workshops**
- **Design report**
  - **530 pages between conceptual design and engineering design**
  - **Access at** www.classe.cornell.edu/ERL/PDDR
- **Also**
  - **Electron beam construction (from RI)**
  - **Cryoplant (from Linde and Air Liquide)**

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7-cell cavity production

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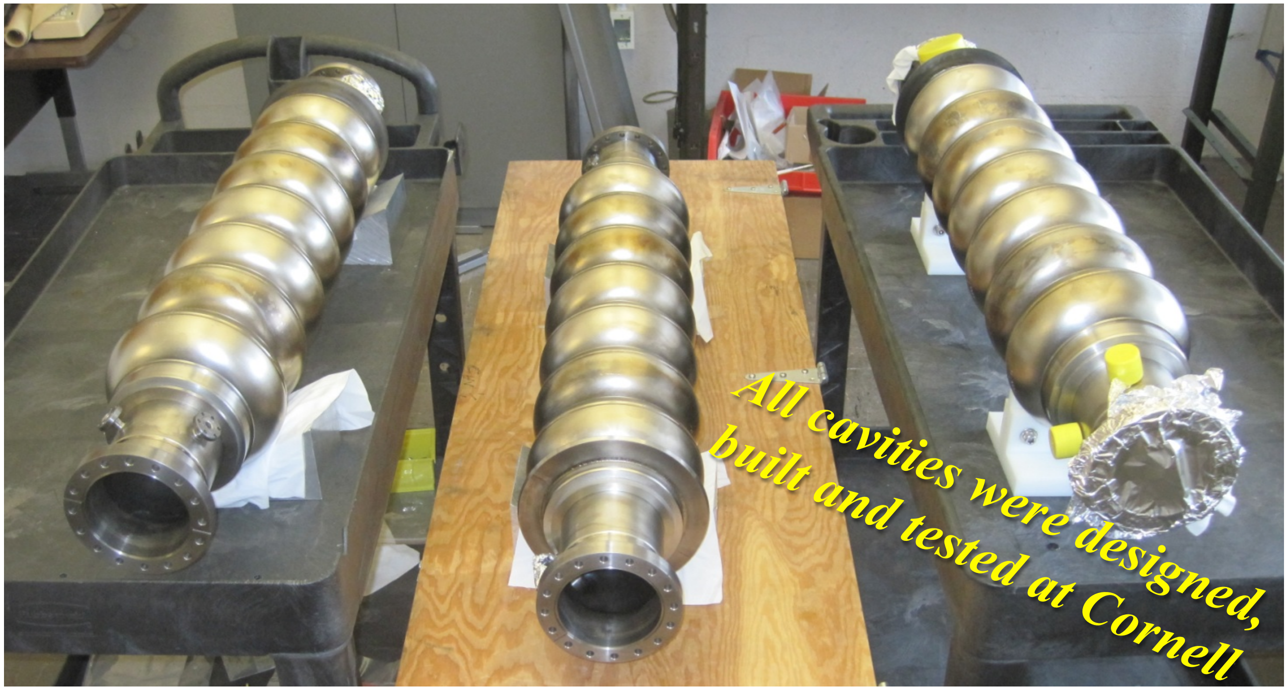
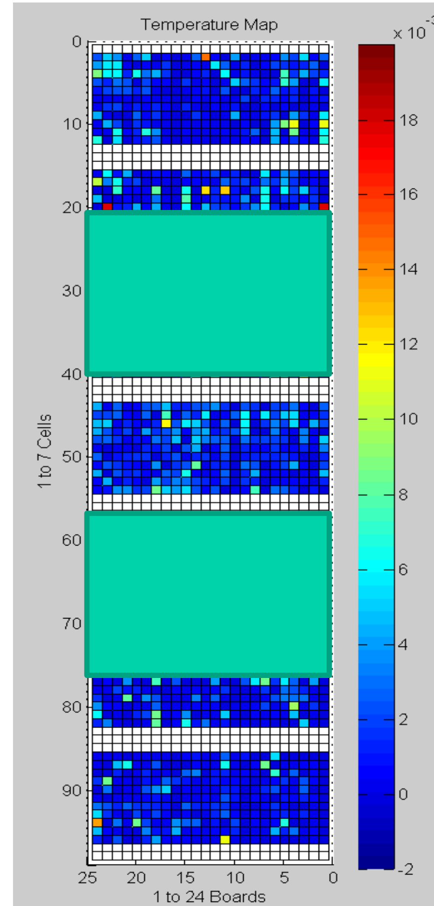


Un-stiffened cavities
(#2, #3, #4)

<ins>ERL 7-cell surface preparations</ins>

1. Bulk BCP (140um)
2. Degassing in TM furnace (650C*4days)
3. Freq. and flatness Tuning
4. Final BCP (10um)
5. 120C bake in TM furnace (120C*48hrs)
6. HF rinse
7. VT w/ T-map



Every test is done with multi-cell T-mapping.

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Vertical test of ERL Cavities

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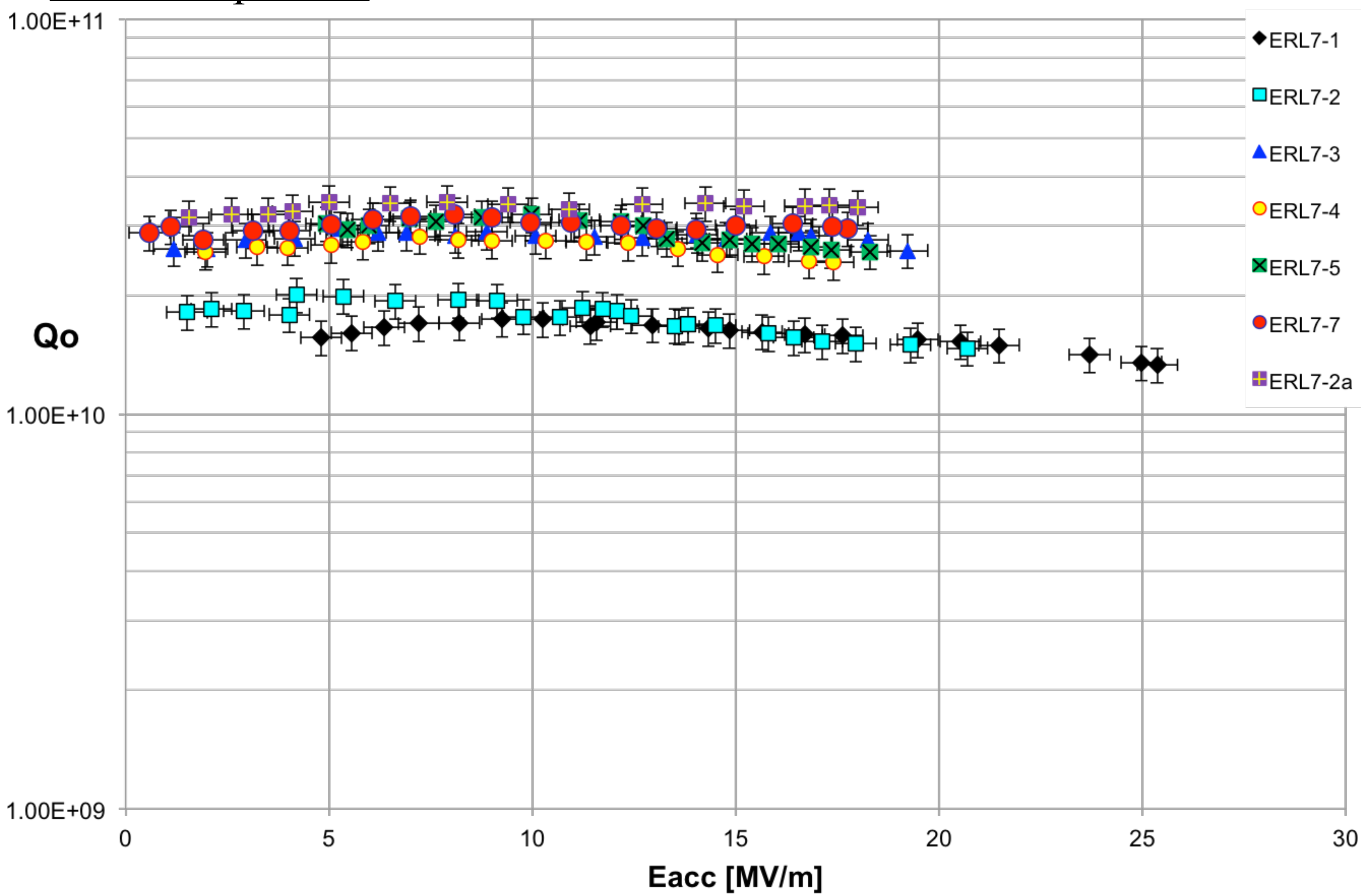
1.8K comparison



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Latest vertical test
B-shielding, no return current

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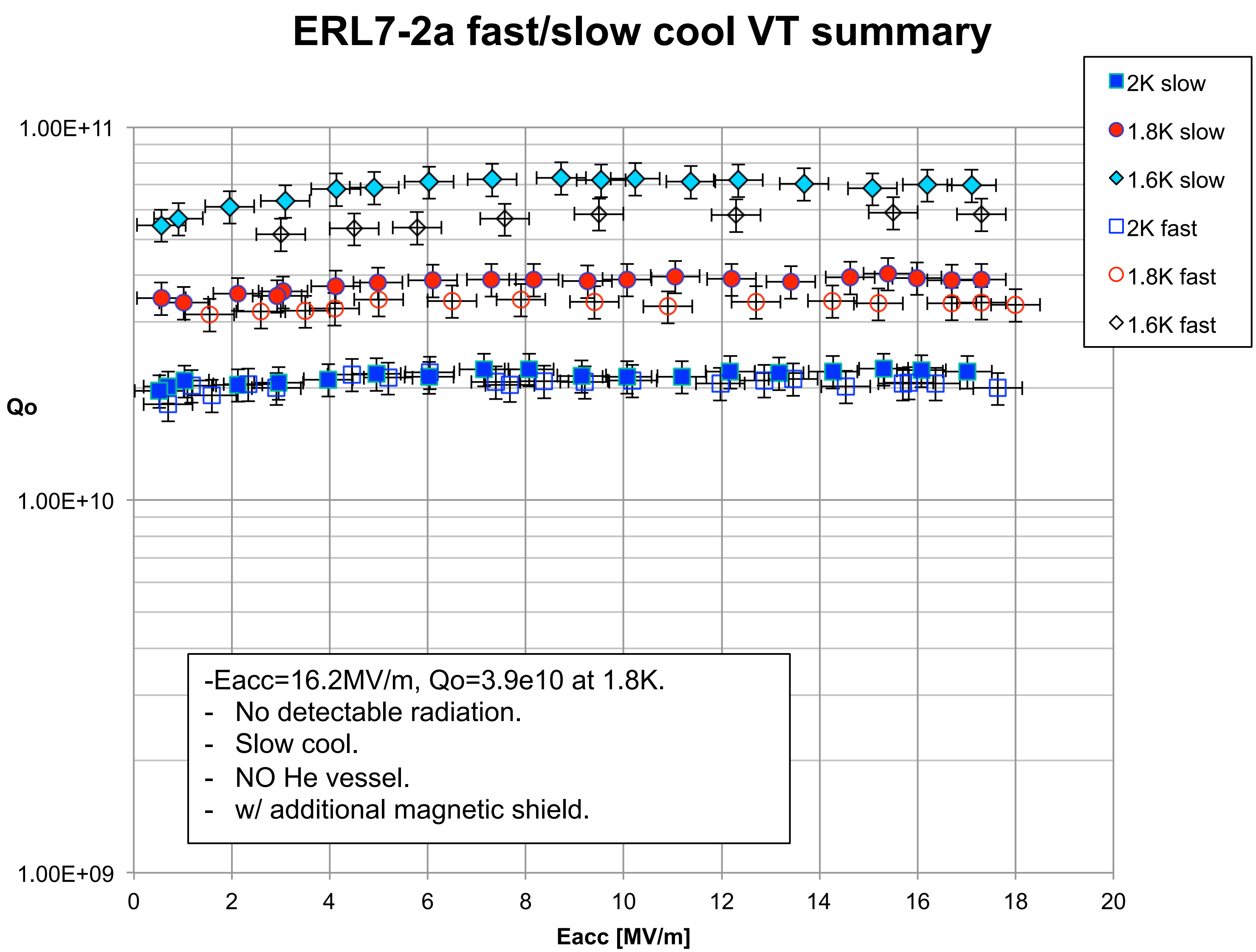
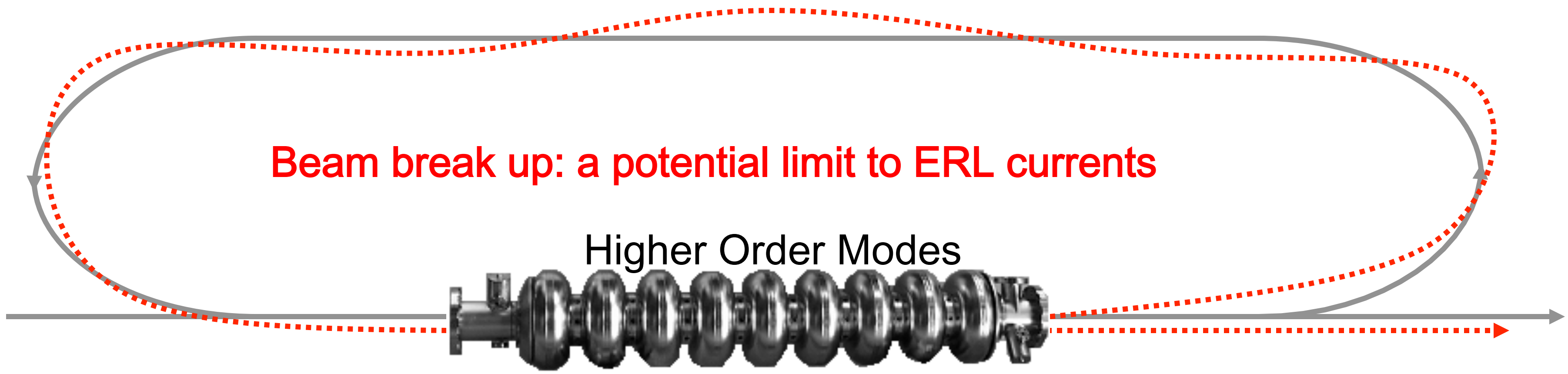


Beam-Breakup (BBU) Instability



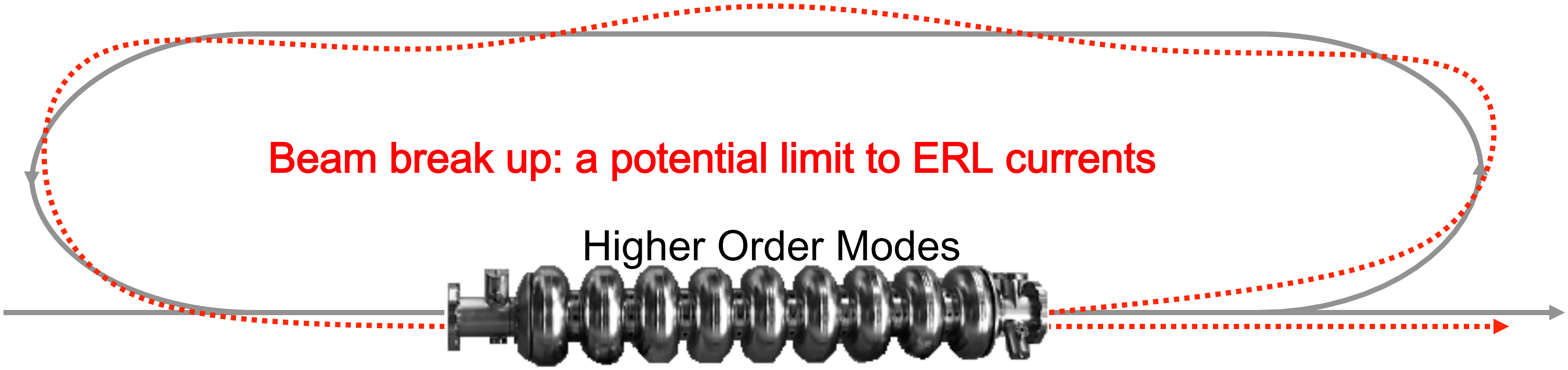
$$V_x(t) = T_{12}\,\tfrac{e}{c}\int_{-\infty}^{t} W_x(t-t')V_x(t'-t_r)I(t')dt'$$

HOMs start orbit oscillations. The returning beam then has an offset that adds energy to the HOM => exponential HOM buildup.

HOM damper have to remove at least the added energy.

Beam-Breakup (BBU) Instability

Beam break up: a potential limit to ERL currents



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Beam-Breakup (BBU) Instability

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Beam break up: a potential limit to ERL currents

$$V_x(t) = T_{12}\,\tfrac{e}{c}\int_{-\infty}^{t} W_x(t-t')\,V_x(t'-t_r)\,I(t')\,dt'$$

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Cavity Design Overview

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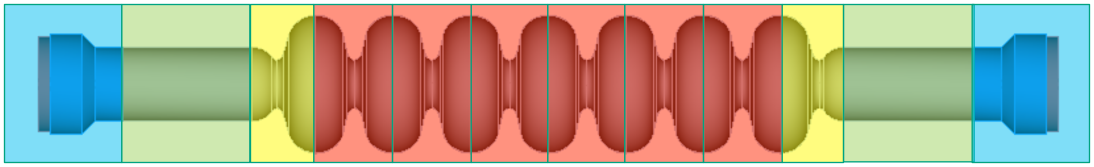

Goal: Maximize I_{th} > 100 mA (under constraints)

Center cells

- Geometries are (nominally) identical high-BBU-current geometries
- Responsible for general properties of HOM spectrum
- Controls frequencies of HOM passbands and dispersion relations
- Determines cell-to-cell coupling and how sensitive HOM spectrum is to variation in cell shape

End cells

- Asymmetric can be used to prevent trapped modes
- Responsible for coupling HOMs to HOM absorber
- Directly controls quality factors of HOMs

Beam Pipe

- Should be short to improve linac fill factor but long enough to avoid dissipating too much power from the fundamental mode

HOM load

- Absorber material properties determine specific mode losses.
- Also serves as bellows connecting cavities

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Main Linac HOM Absorbers

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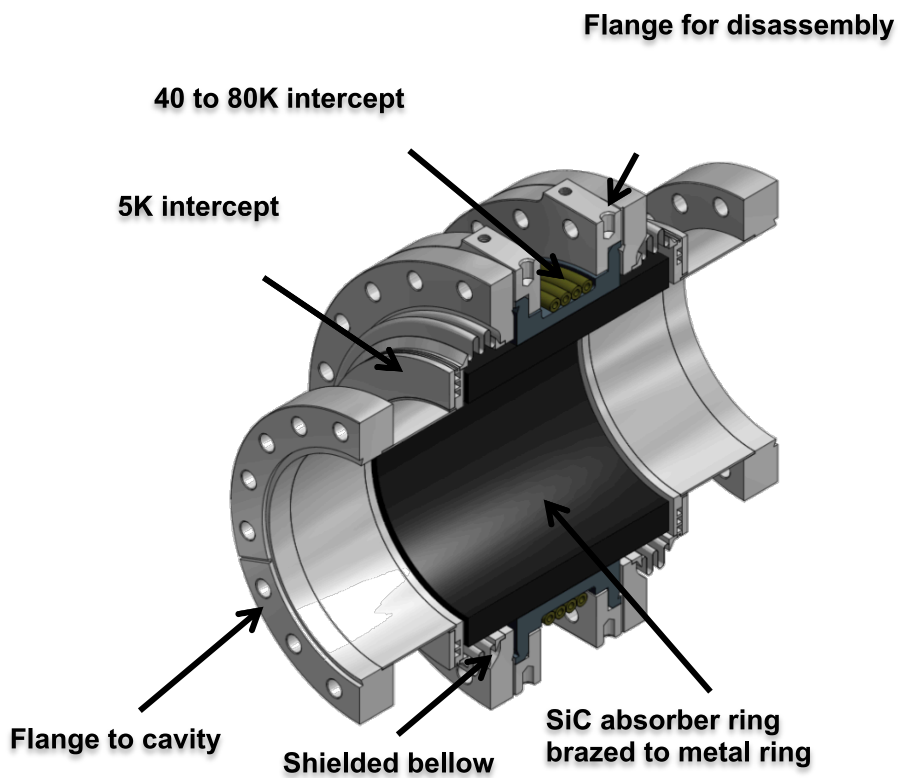

- Full-circumference heat sink to allow >500W dissipation @ 80K
- Broadband SiC absorber ring, brazed to tungsten
- Includes bellow sections
- Flanges allow easy cleaning
- Zero-impedance beamline flanges

Note:
Changes of the Coupler from TTC-III hast been covered in a separate presentation. 7 couplers are tested to 5kW with overhead to 10kW.

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HOM damping in the HTC

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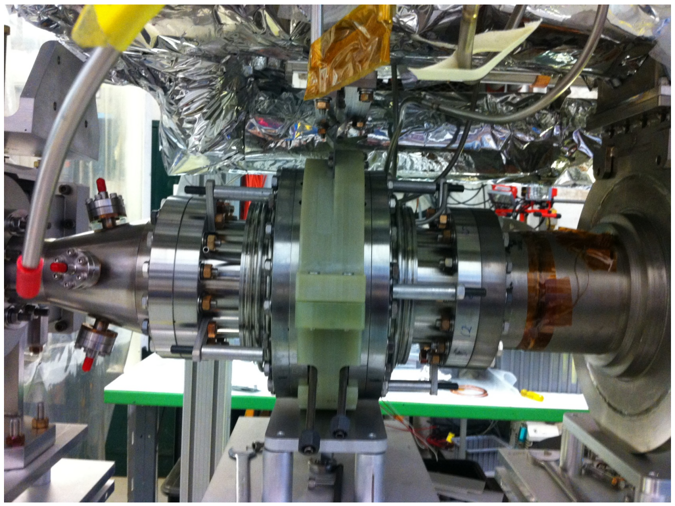
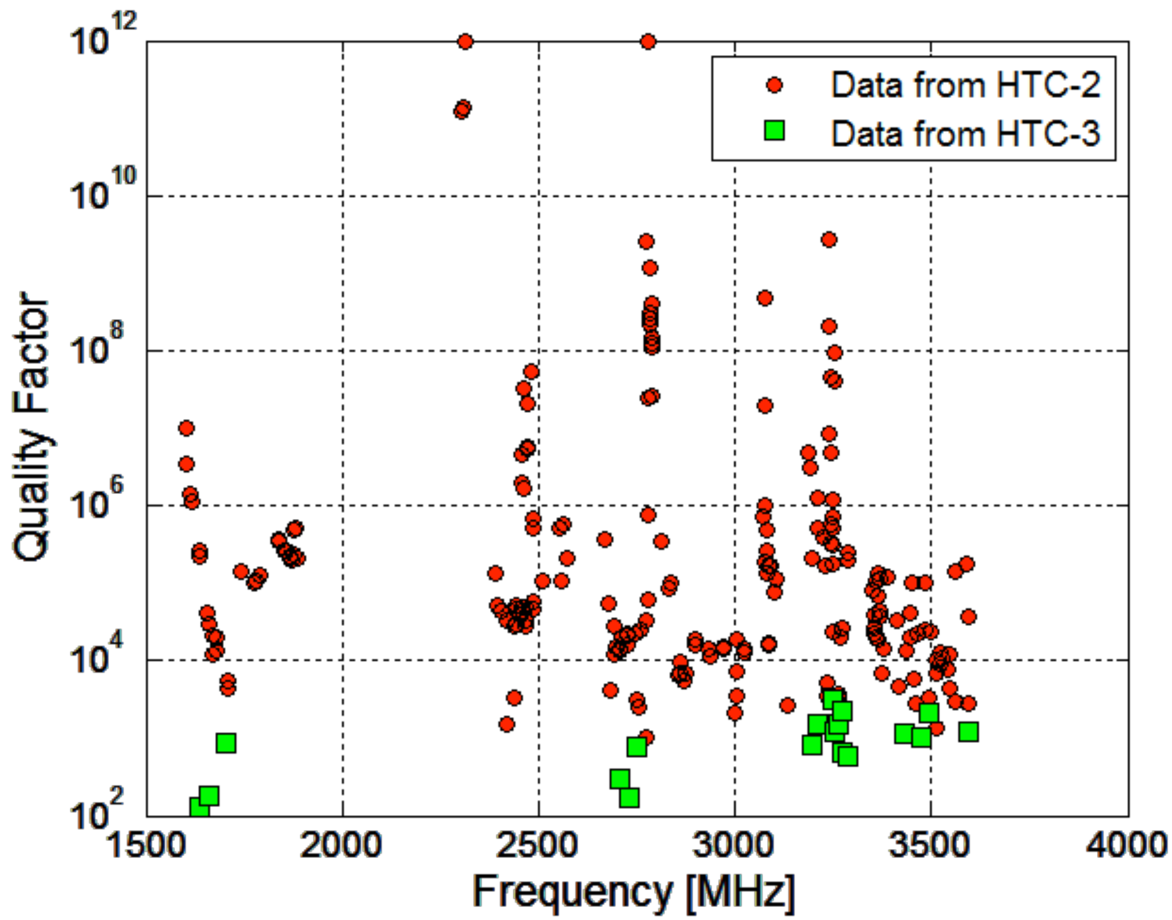


HTC-2: No HOM Absorbers
HTC-3: With HOM Absorbers



Beamline HOM absorbers strongly damp dipole HOMs to under Q ~ 10^4

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HOM measurements in the HTC with beam

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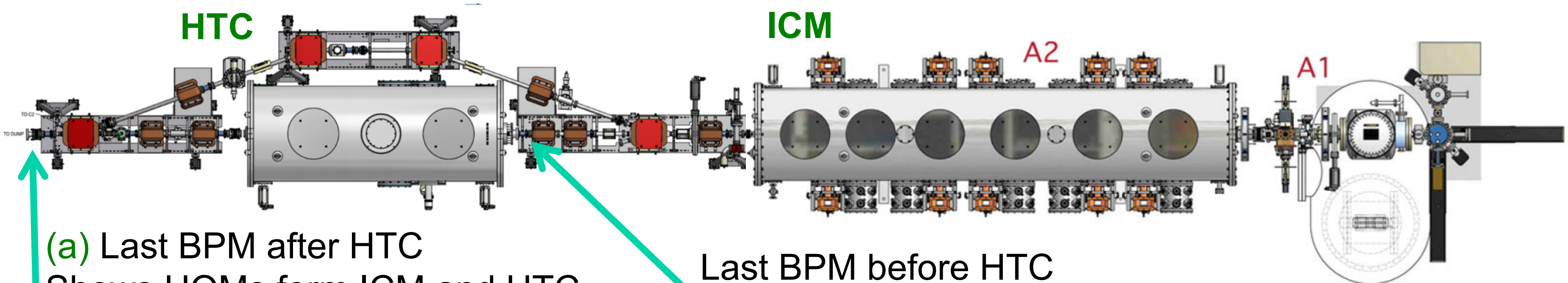


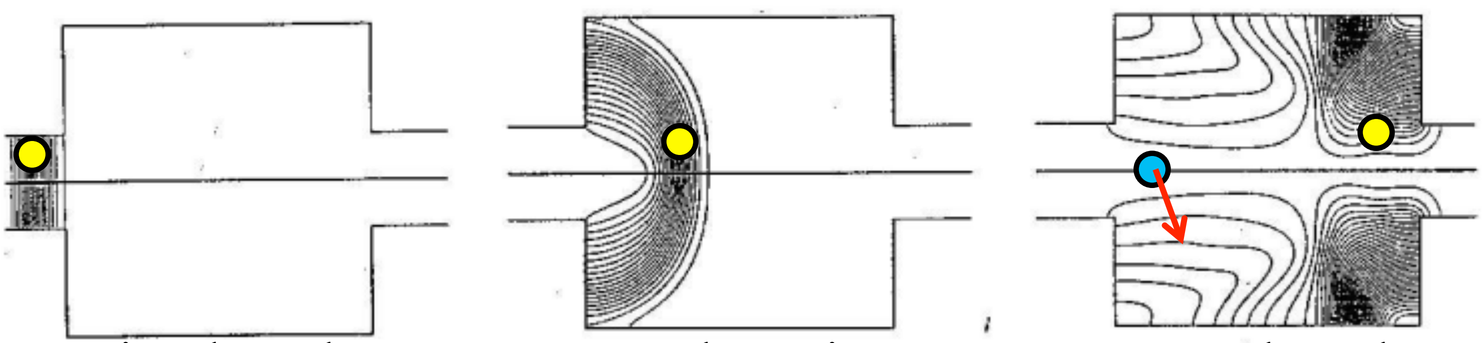
(a) Last BPM after HTC
Shows HOMs form ICM and HTC

Last BPM before HTC
Shows HOMs form ICM to be subtracted from (a)

(A.1) Excitation of HOMS by modulation of beam current

(A.2) See the beam oscillate under these HOMs => f, Q, and R/Q of HOMs => **OK !**

(B) Measure HOM heating => beam-pipe HOM absorbers need copper coating !



First bunch enters cavity | Bunch excites fields | Future bunches receive kick

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ERL Linac Cryomodule Philosophy

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- Use the same cryomodule concept in the injector and the main linac, based on the ILC module.

Reduces risk

- Rely on well established and tested performance of the TTF III technology to reduce risk, cost and minimize development time.
  - Some improvements
  - Cavities supported by large diameter Helium-gas return pipe (HGRP)
  - All cryogenic piping inside of cryomodule
  - Some changes needed
- Further simplify and reduce cost

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Changes compared to ILC CM

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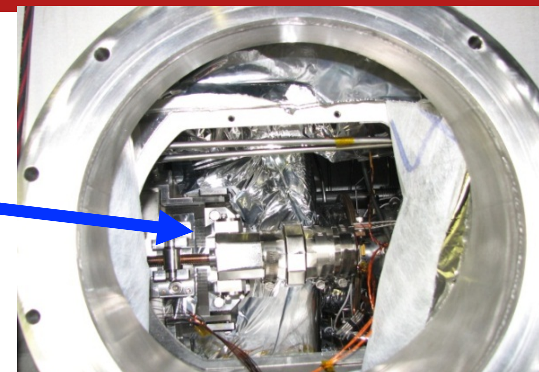
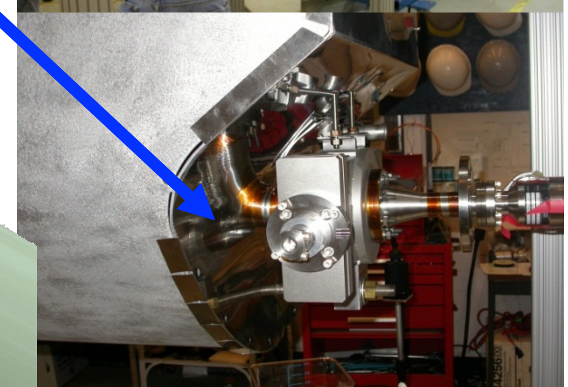
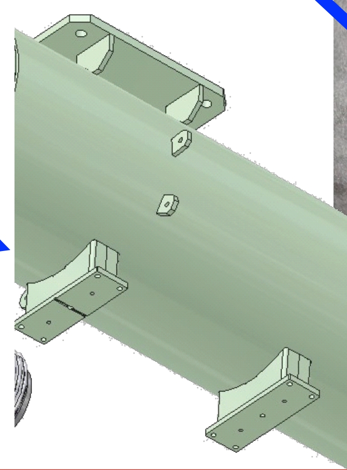
- Implement beamline HOM loads for strong broadband damping of HOMs generated by the high current and short bunches.
- Use a low average power coax RF input coupler per cavity, with lateral flexibility for cool down and fixed coupling.
- Do not include a 5K shield.
- Increase the diameter of the cavity helium vessel chimney to 10 cm for the high CW heat load.
- Include a JT valve in each cryomodule for the high CW heat load.
- Increase the diameter of the 2-phase 2K He pipe to 10 cm for the high CW gas load.

Design "Innovations"

- Tuner stepper replaceable while string is in cryomodule
- Rail system for cold mass insertion
- Gate valve inside of module with outside drive
- Precision fixed cavity support surfaces between the beamline components and the HGRP -> easy "self" alignment







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Structural analysis

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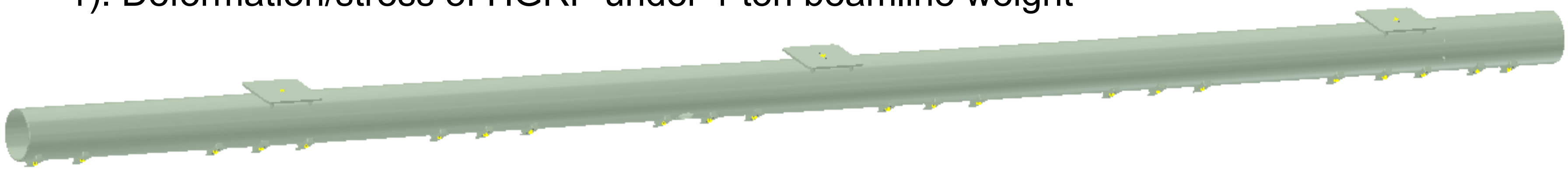
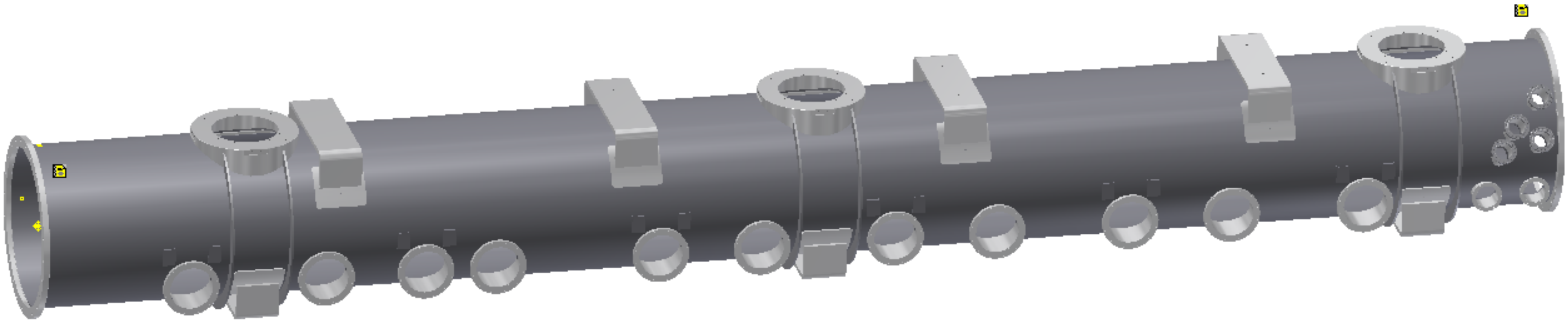
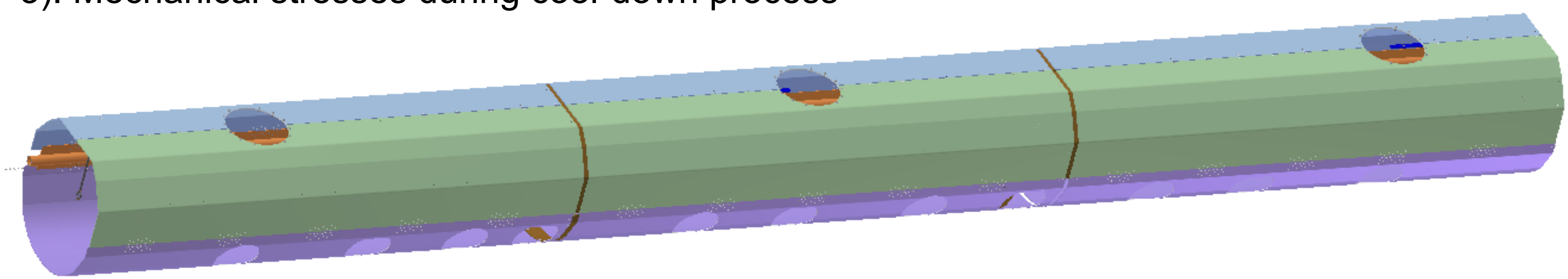
1). Deformation/stress of HGRP under 1 ton beamline weight



2). Deformation/stress of vacuum vessel with 4 ton cold mass weight on 3 support posts



3). Mechanical stresses during cool-down process



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Structural analysis

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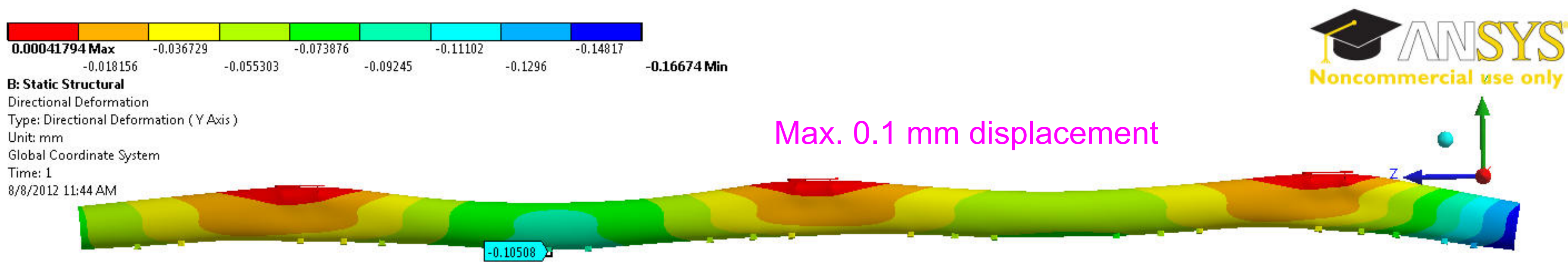
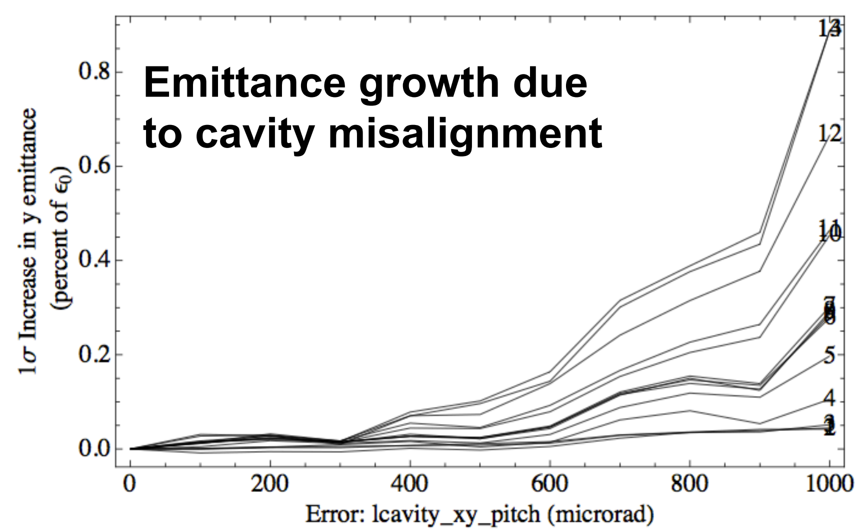


Cavity Alignment:

- Transverse offset (x,y)
  - Baseline (1-σ): 0.5 mm
  - Allowable (1-σ): 2 mm
- Pitch
  - Baseline (1-σ): 1 mrad
    (0.8 mm over length of cavity)
  - Allowable (1-σ): 1.5 mrad
    (1.2 mm over length of cavity)



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Structural Analysis

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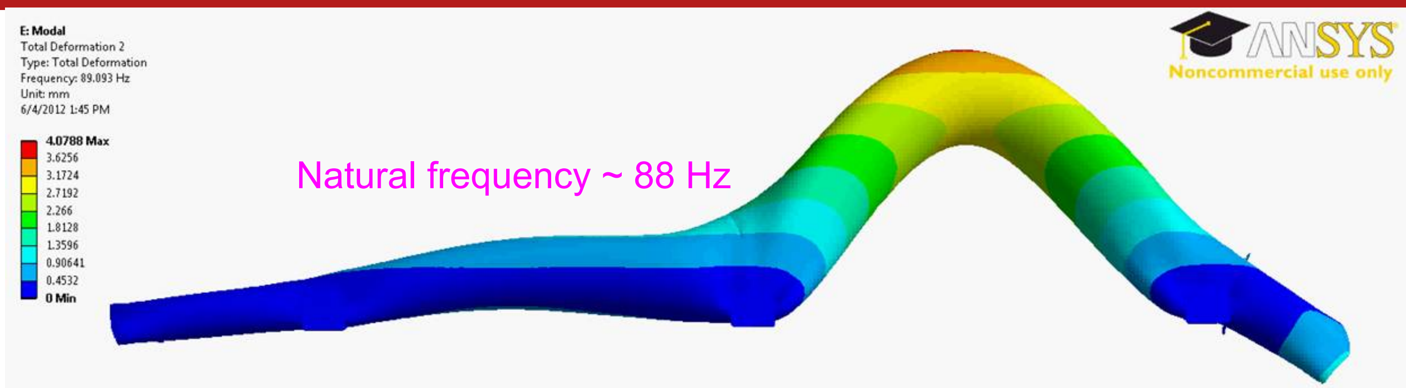

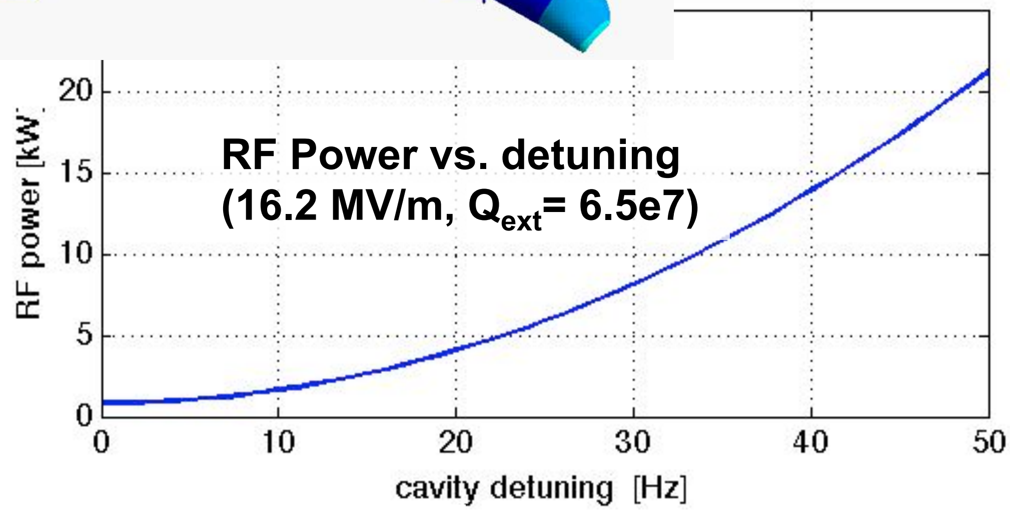

Table 2.4.3: Measured microphonic levels measured in SRF Linacs [12].

machine	σ (Hz)	6σ (Hz)	Comments
CEBAF	2.5 (average)	15 (average)	significant fluctuation between cavities
ELBE	1 (average)	6 (average)	
SNS	1 to 6	6 to 36	significant fluctuation between cavities
TJNAF FEL	0.6 to 1.3	3.6 to 7.8	center cavities more quiet
TTF	2 to 7 (pulsed)	12 to 42 (pulsed)	significant fluctuation between cavities

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Cryogenic sketch of one Module

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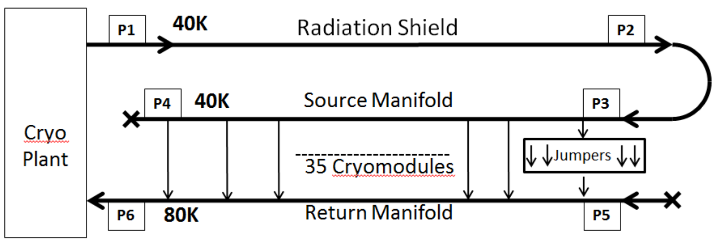
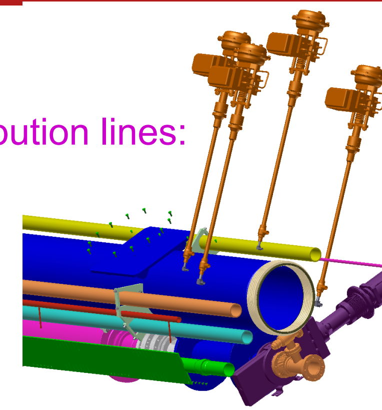
2K, 5K and 40K supply pipes run for the entire half linac

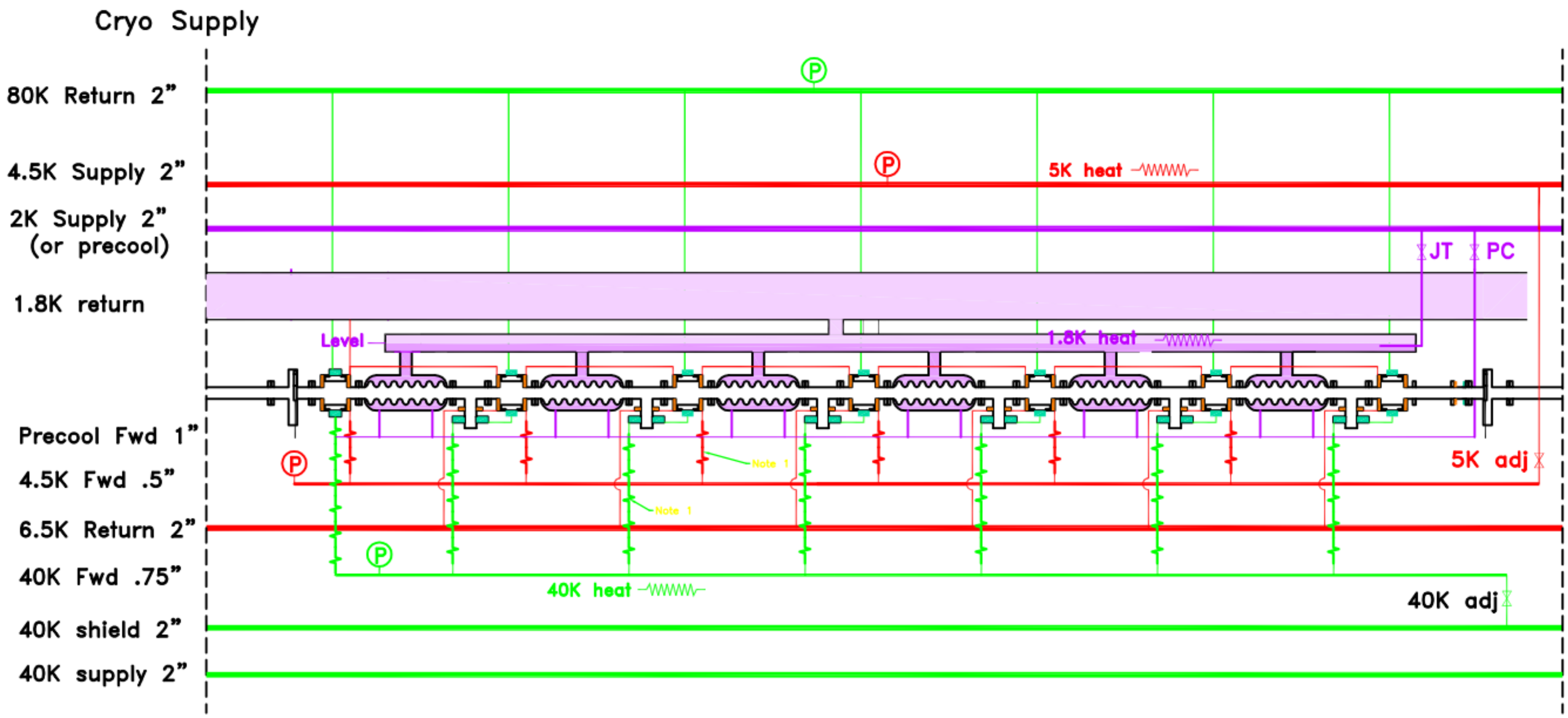


4 Valves control flow into local distribution lines:

- 1.8 K
- Pre-cool
- 5 K
- 40 K



Inside each cryomodule



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Cryogenic manifolds: six lines

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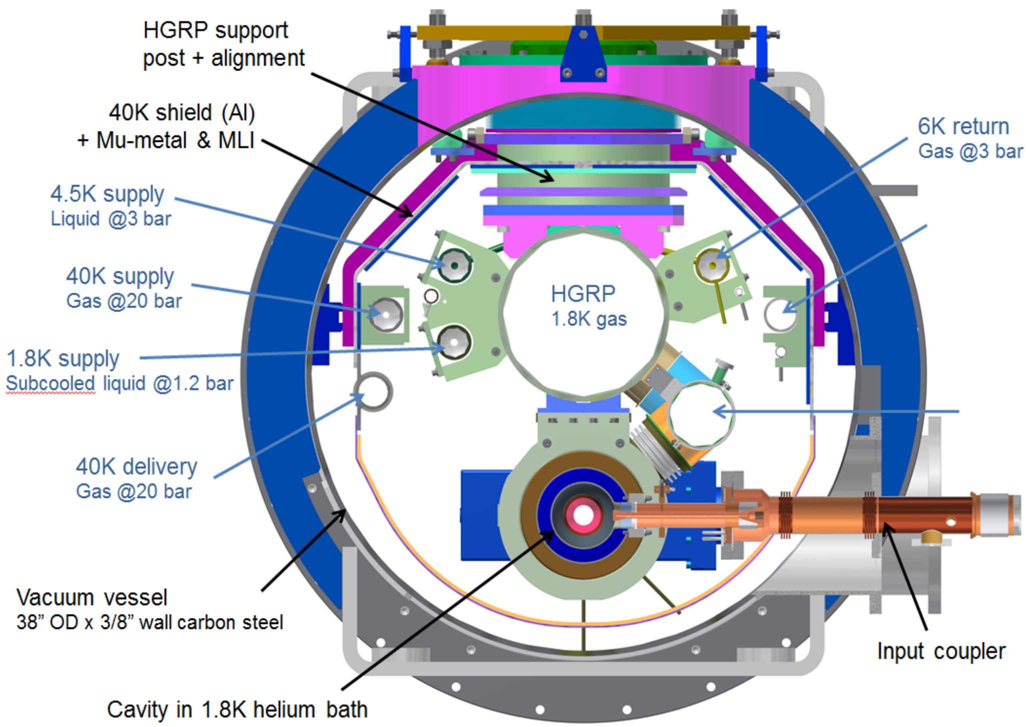
1 line for 2K supply	subcooled liquid @1.2 bar	• 2K helium bath for cavities via 2K-2 phase line • pre-cool gas for cool-down • 90% heat load from RF losses in the cavities
2 lines for 4.5-6K	3.0 bar He liquid Single phase flow	• Thermal intercept for HOM absorbers and couplers • 2/3 dynamic heat load
3 lines for 40-80K	20 bar He gas	• Thermal intercept for HOM absorbers and couplers • 40K thermal shield, low thermal expansion rate over 40-120K range • 90% heat load from HOM



Start of discussion