A 100 MV Cryomodule For CW Operation

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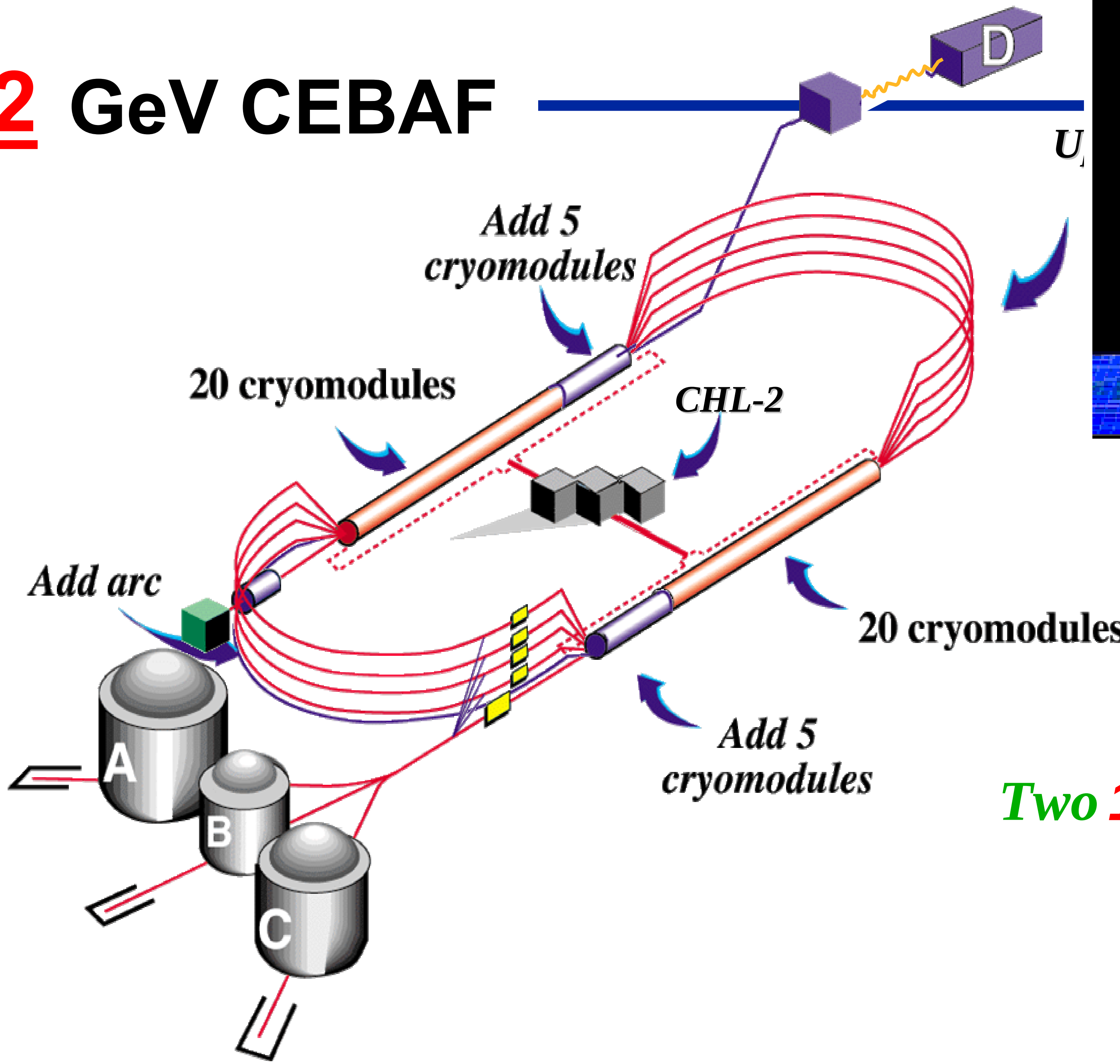
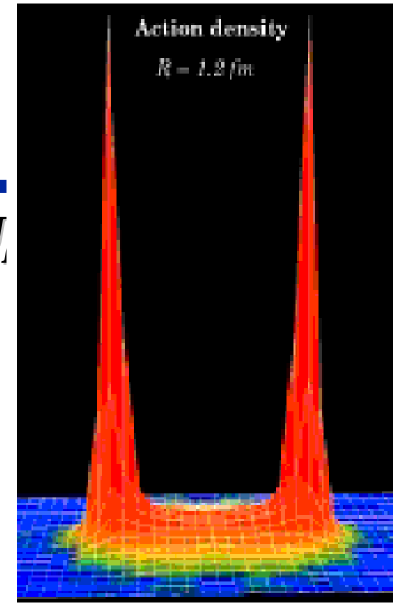
SRF Workshop, July 11, 2005

12 GeV CEBAF





*Two **1.1** GV linacs*

Cryomodule Requirements for 12 GeV CEBAF

Ten new CW cryomodules are required

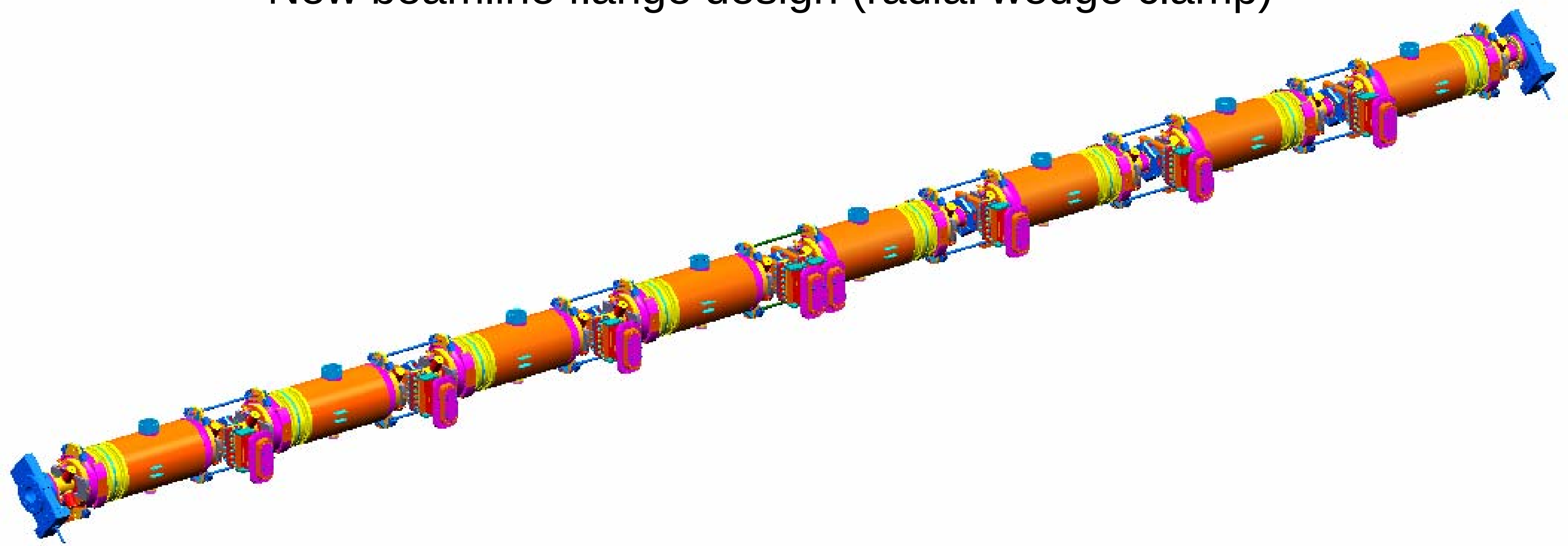
- Voltage: ≥ 109 MV CW, 1497 MHz
- Heat budget:
  - — 2.07 K ≤ 300 W (26 W static, 241 dynamic, 33 W contingency) (29 W/cavity + 9 W input couplers)
  - — 50 K ≤ 300 W
- Tuner resolution: ≤ 2 Hz
- FPC: 7.5/13 kW
- HOM damping: $Z < 6 \times 10^8\ \Omega$, dipoles, to avoid BBU
- Length ~8.5 m between beamline flanges

Evolution of CEBAF CW Cryomodule Design Parameters

- 1st Prototype – (SL21) installed in CEBAF South Linac
  - CEBAF Cavity Shape with 2 HOM couplers
  - Al-Mg Seals on beamline
  - 8 kW Waveguide
  - New Tuner Design with coarse and fine tuning capability
  - Implemented space frame concept
  - Re-used end can design (200 W rating)
- 2nd Prototype – (FEL03) installed in FEL
  - Improved piping design
  - Added He-II heat station to FPC waveguides
- 3rd Prototype – (Renascence) built and ready for testing
  - Implemented High-Gradient and Low-Loss cavity shapes with 4 HOM couplers
  - Improved HOM feedthroughs
  - Cold Tuner (coarse/fine)
  - 13 kW Waveguide
  - Revised Helium Vessel Design
  - Low-profile Radial-Wedge flange on beamline
  - Improved Thermal Shield Design
  - Incremental improvements to vacuum vessel for fiducialization
  - End cans useable up to 350 W (verified by testing)
  - Serpentine-shaped Al-Mg gasket on FPC rectangular waveguide
  - All Al-Mg Seals (no indium)

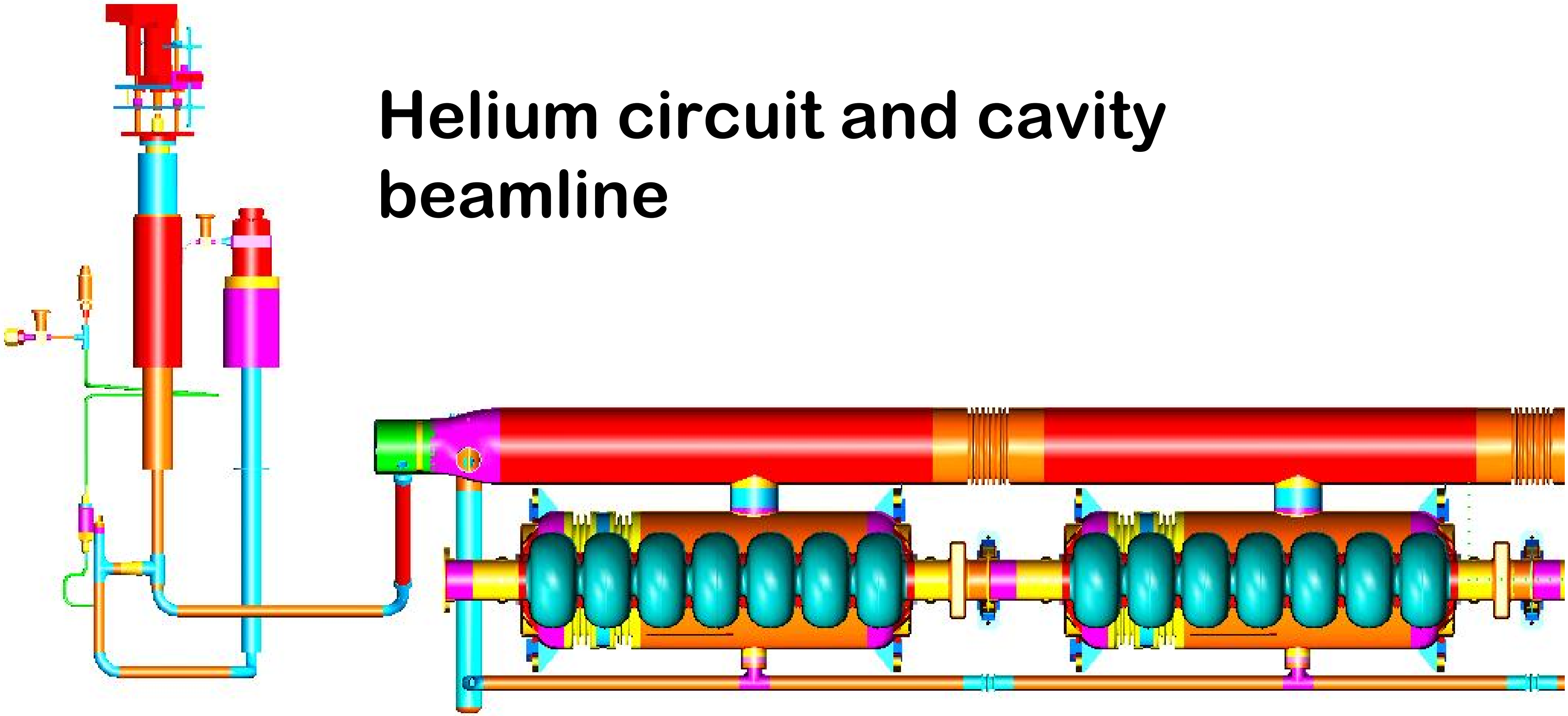
Cryomodule Design Overview

- **Cavity String**
  - Compact beamline design enables 5.6 m active cavity length between beamline flanges 8.5 m apart
  - 8 cavities with hermetic sealing valves on end of string
  - No inter-cavity bellows
  - New beamline flange design (radial wedge clamp)



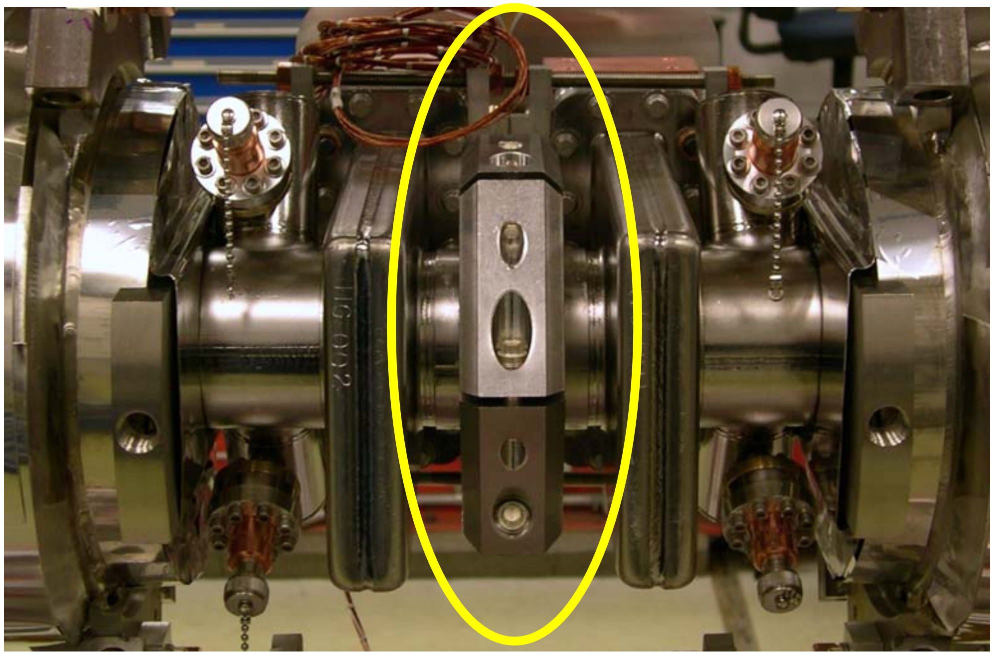
Renascence-style Cold Mass

Helium circuit and cavity beamline

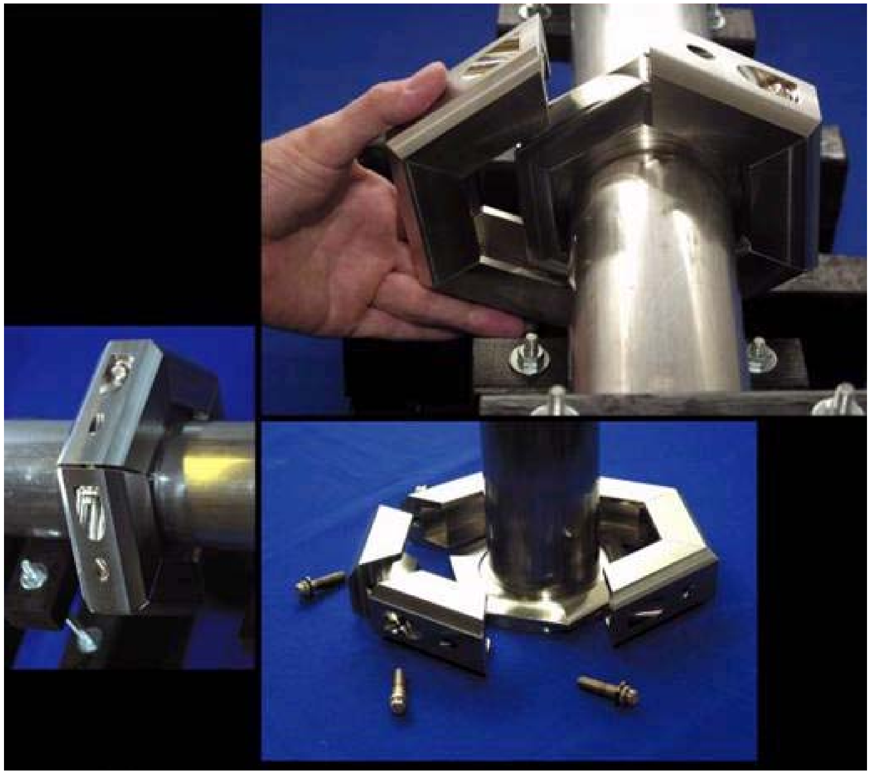


Flange sealing improvements

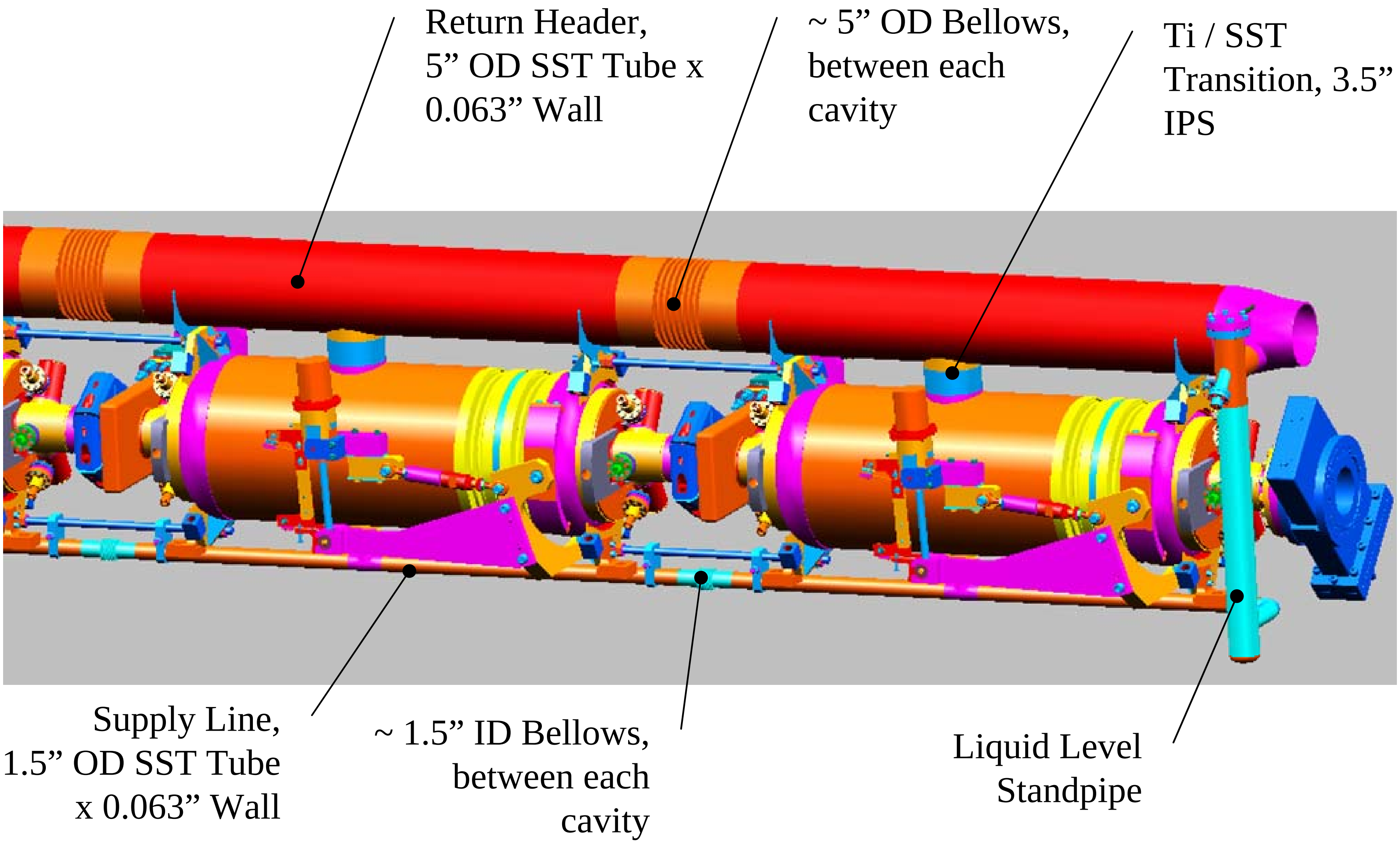
- **Radial wedge clamp**
  - **Low profile for beamline flanges**



US Pat. # 6,499,774

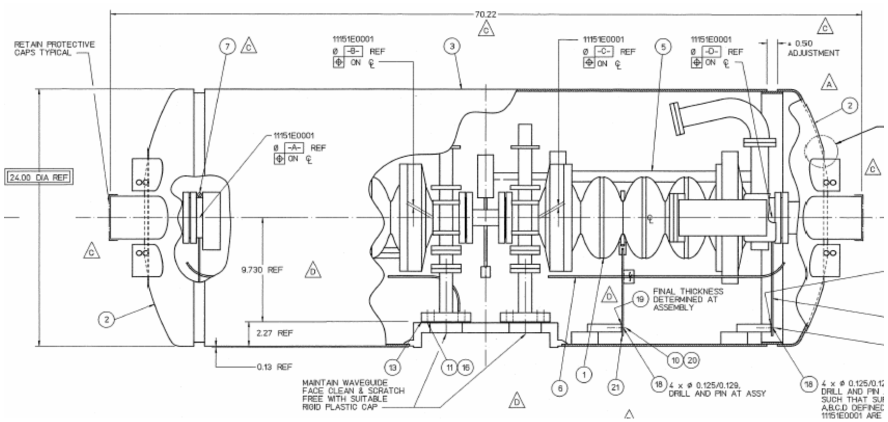


LHe Header Piping



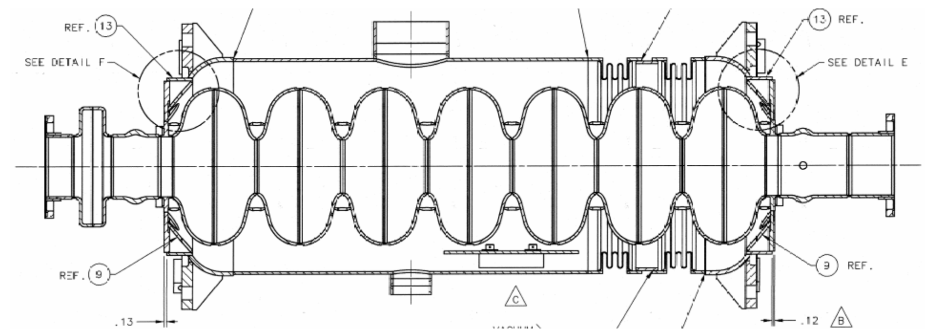
Comparison : Original & Upgrade Helium Vessels

CEBAF Helium Vessel Assembly



- Two cavities per helium vessel
  - Five cells per cavity
- Indium vacuum seals
  - Beamline components
  - Beamline-to-helium
  - Beamline-to-insulating vacuum
- Bellows between cavity pairs
- Tuner mechanism immersed in liquid helium

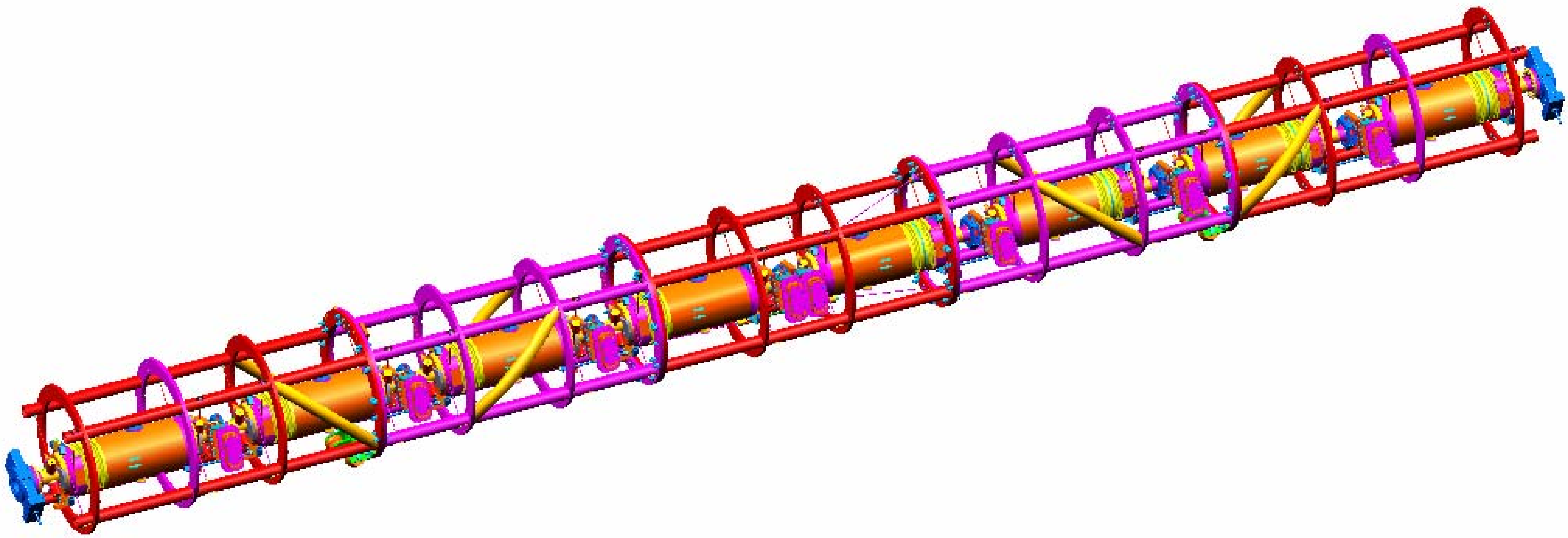
Upgrade Helium Vessel Assembly



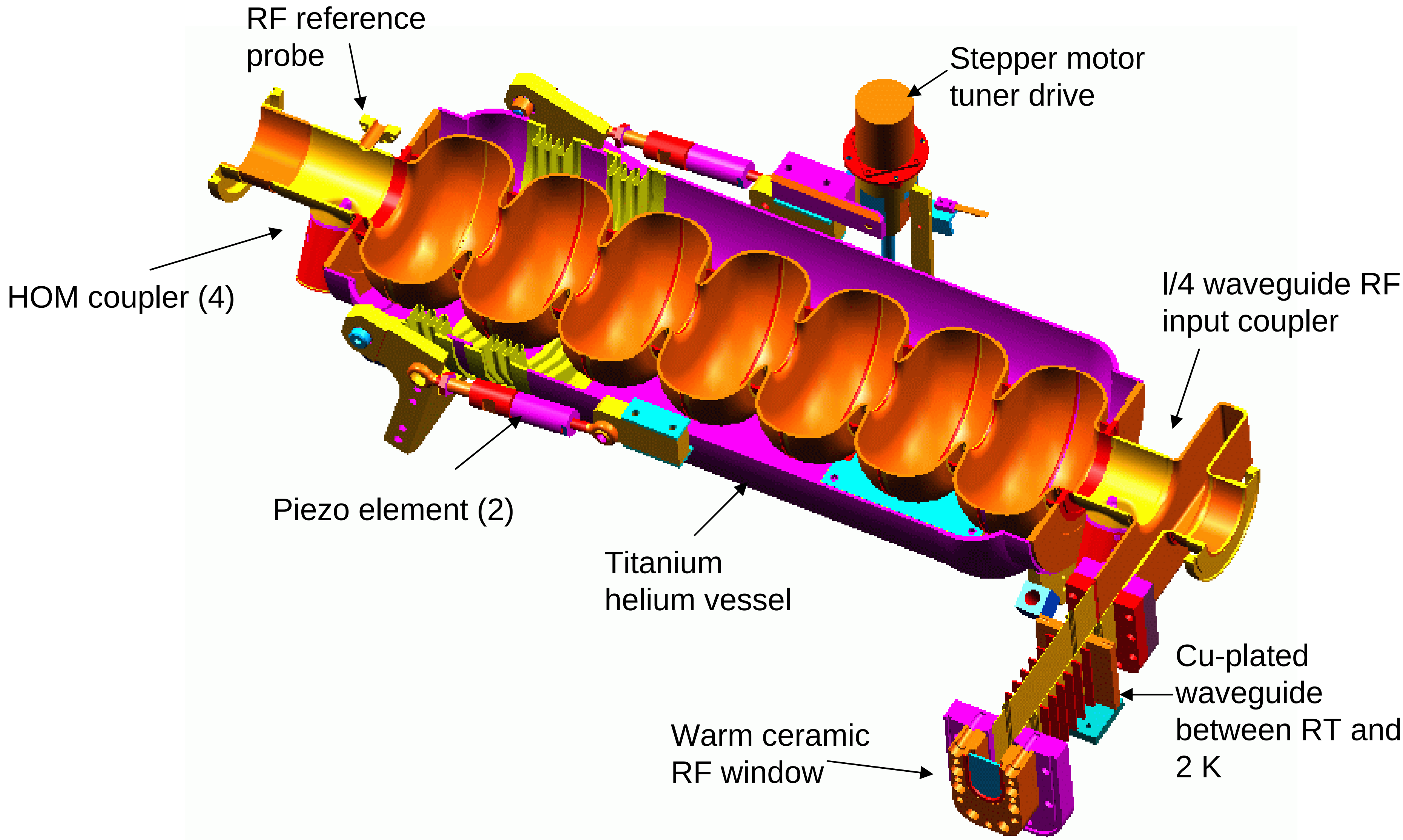
- One cavity per helium vessel
  - Seven cells per cavity
- Hard metal vacuum seals
  - Beamline components
  - Beamline-to-insulating vacuum
  - Beamline-to-air (FPC)
- No bellows between cavities
- Tuner mechanism in insulating vacuum space

Cryomodule Design Overview

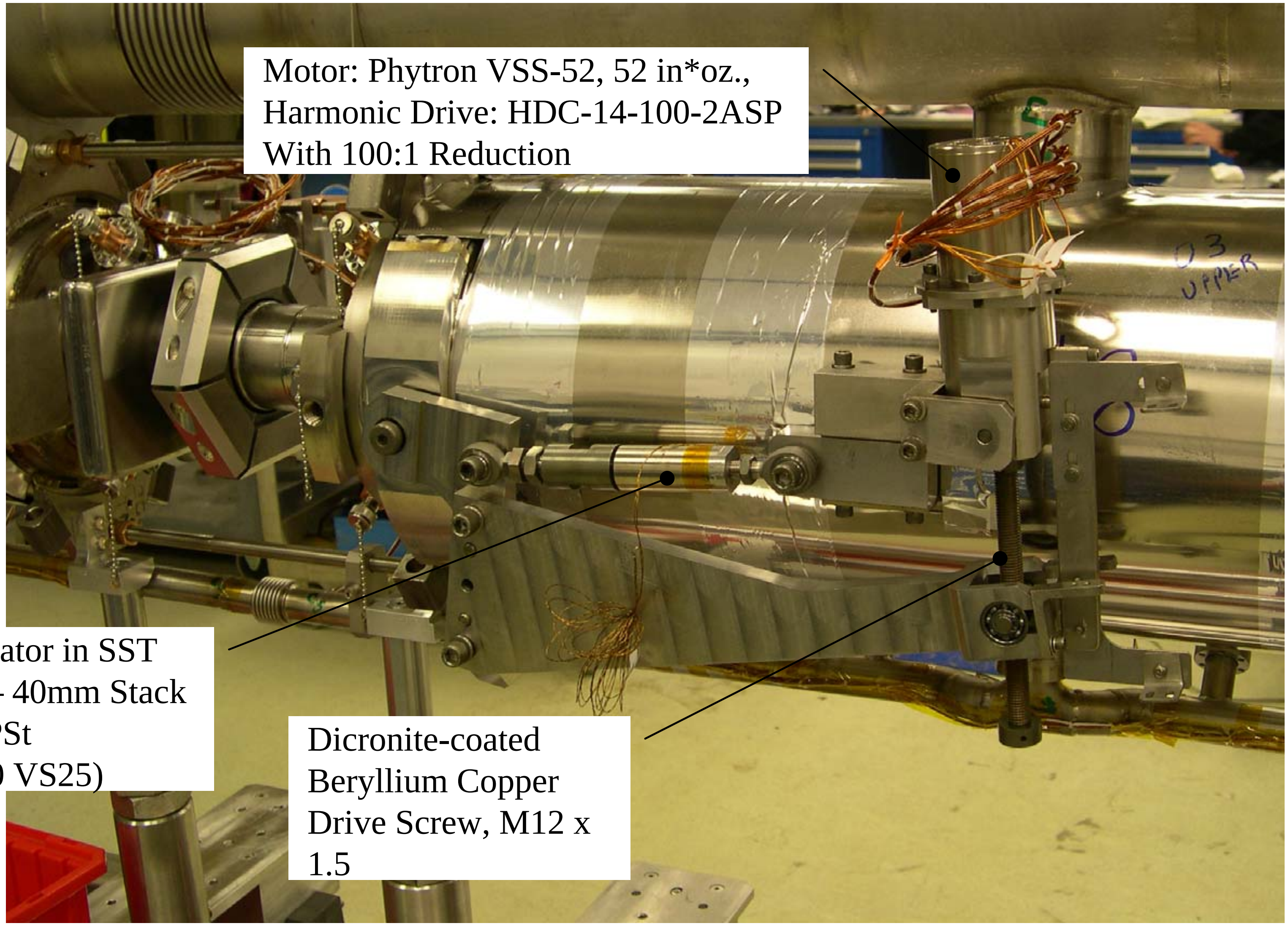
- **Internal support structure - Space Frame**
  - —Cold Mass Support (cavities, helium distribution, shields, …)
  - —Cavity Alignment relative to fiducials
  - —Roll in and out of vacuum vessel



LL Cavity System



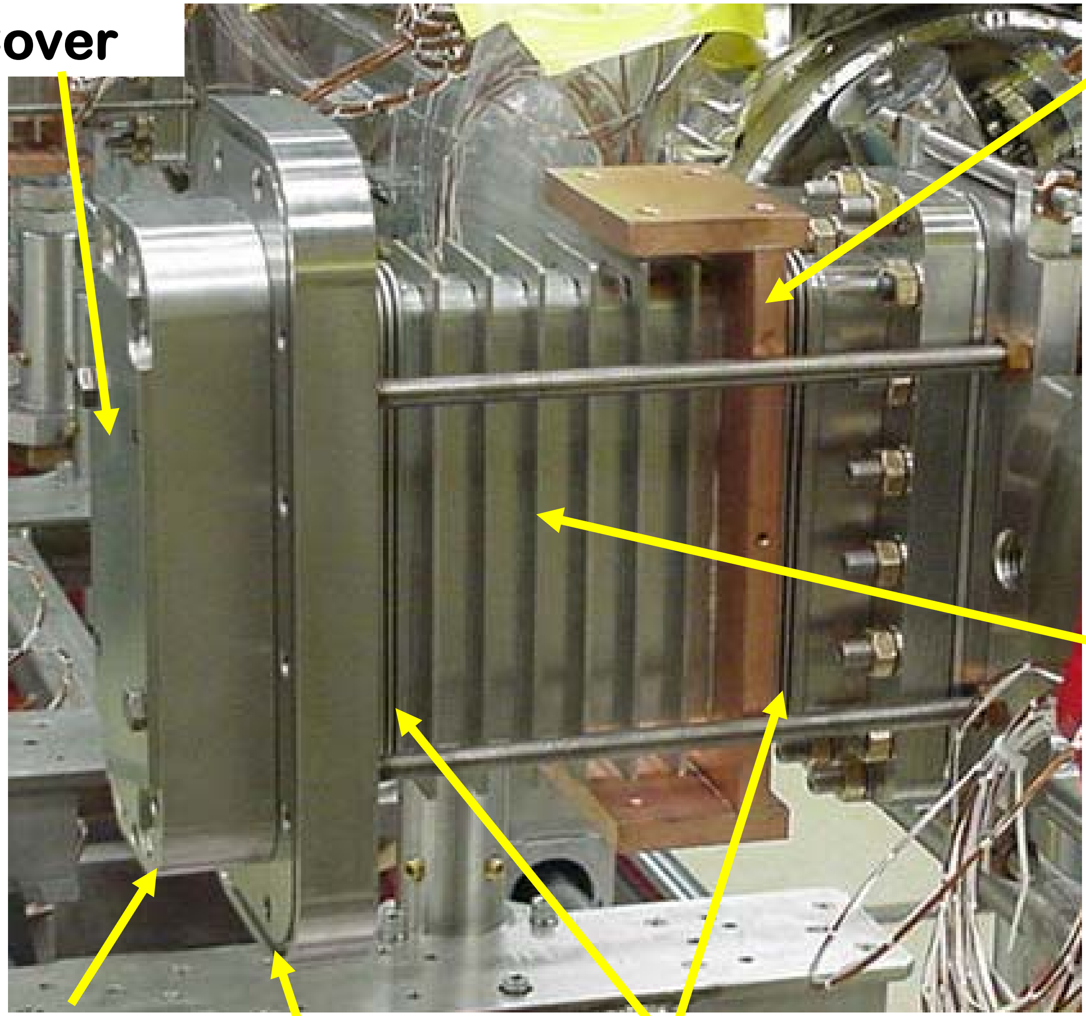
Tuner and Helium Vessel Assy

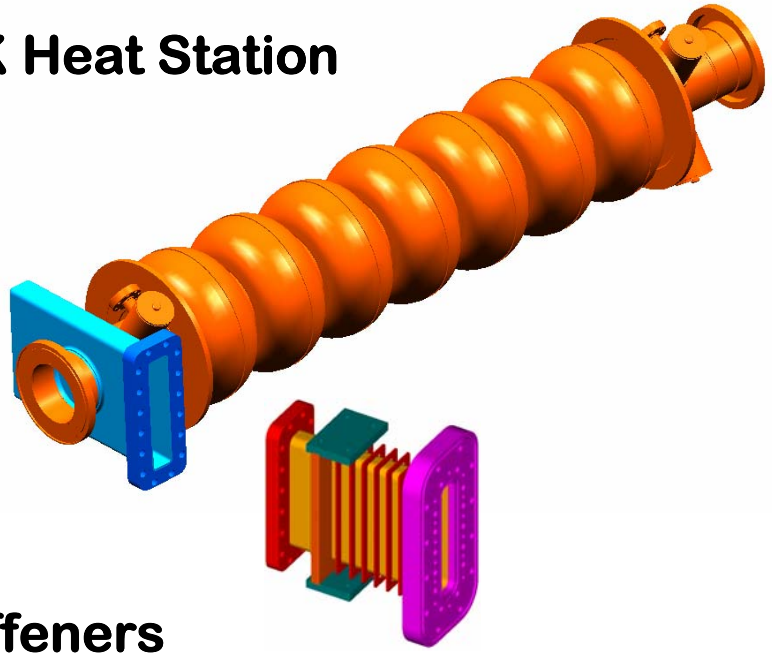


Tuner Requirements

Parameter	Requirement	Actual
✓ Range (kHz)	400	1000
✓ Resolution (Hz)	< 100	< 3
✓ Backlash (Hz)	< 25	< 10
Piezo Range (Hz)	1000	1200 (est.)
✓ Piezo Resolution (Hz)	< 1	< 1 (est.)
✓ Cyclic Life		
Mechanical Tuner	29×10^3 (2x/day, 365 day/yr, 40 yrs)	
Piezo Actuator	7.0×10^6 (20x/hr,24 hr/day, 365 d/yr, 40 yrs)	
✓ Radiation Limit (rads)	$> 10^6$	$> 10^8$
✓ Tuning Method	Tension	-
✓ Load at full stroke (kN)	14.0	~ 22.2
✓ Travel (mm)	2	3.3

Input RF Waveguide





Renascence Waveguide

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Office of Science
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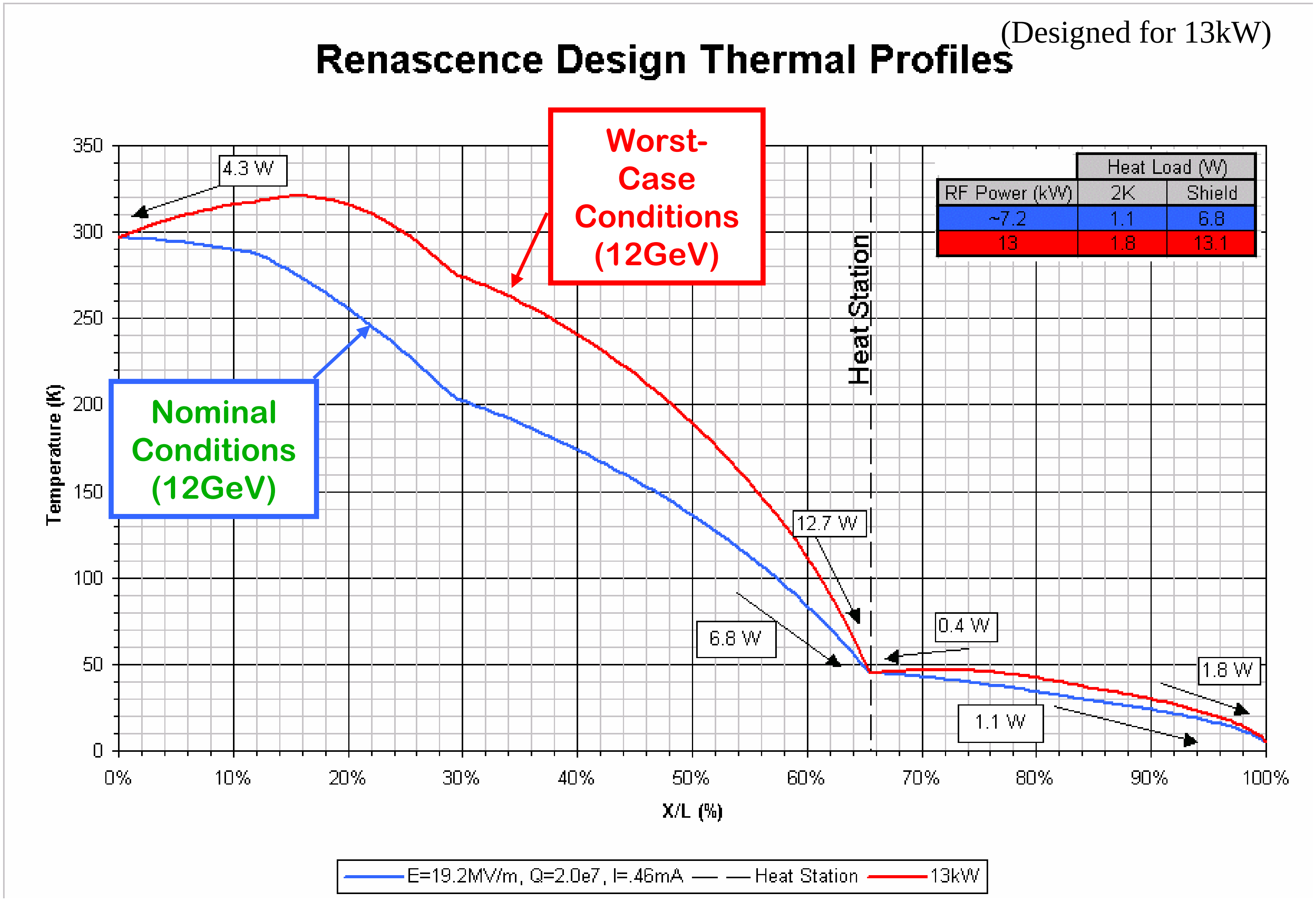
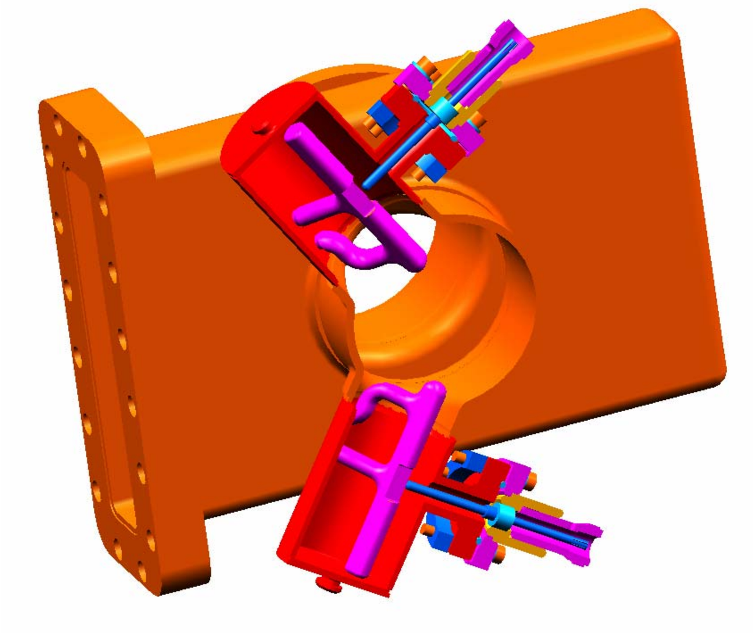
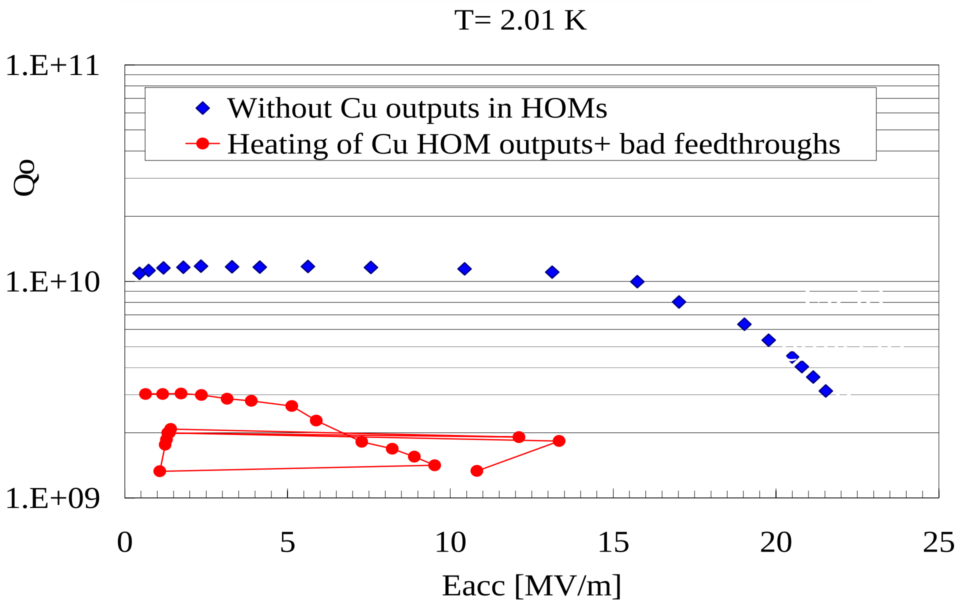
Thermal Analysis of Input RF Waveguide



HOM coupler probe/feedthrough

- **DESY-style HOM coupler depends on resonant rejection of the fundamental.**
  - — $Q_{e\text{-fundamental}} > 3\times10^{11}$
  - — Typical $Q_{e\text{-fundamental}} > 1\times10^{12}$
- **Operation of the SNS cavities with CW RF had serious heating problems with the HOM couplers – probes were Cu, weak thermal conduction through the sealing dielectric.**
- **HOM couplers (4) were moved closer to end cells in HG and LL for maximum damping.**
- **The pickup probe is exposed to significant fundamental fields (10% of H_{max}), so must be superconducting and thermally stabilized.**
- **Initial testing of Renascence prototypes with Cu HOM coupler probes showed serious Q degradation and long thermal time constants.**

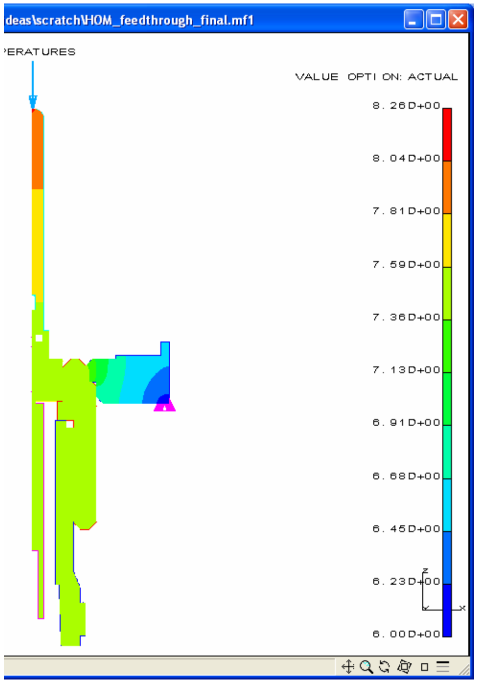




HOM coupler probe/feedthrough

- Heat load (BCS) on Nb probe in HG & LL cavity at 20 MV/m CW:
  - 2 - 5 mW @ 6 K
  - 11- 20 mW @ 8 K
- Feedthrough thermal conduction is critical
- Testing and FE modeling of three designs:

RF Feedthrough Design	T_{tip} @ 10 mW	T_{tip} @ 20 mW	
Kyocera design used on TTF and SNS (pulsed RF)	> 13 K	16 K	Not viable !
JLab/CeramTech design	5.5 K	< 9.2 K	Acceptable and demonstrated
JLab sapphire-dielectric design	< 5 K	< 6.9 K	Confidently better, and available



Used on Renascence

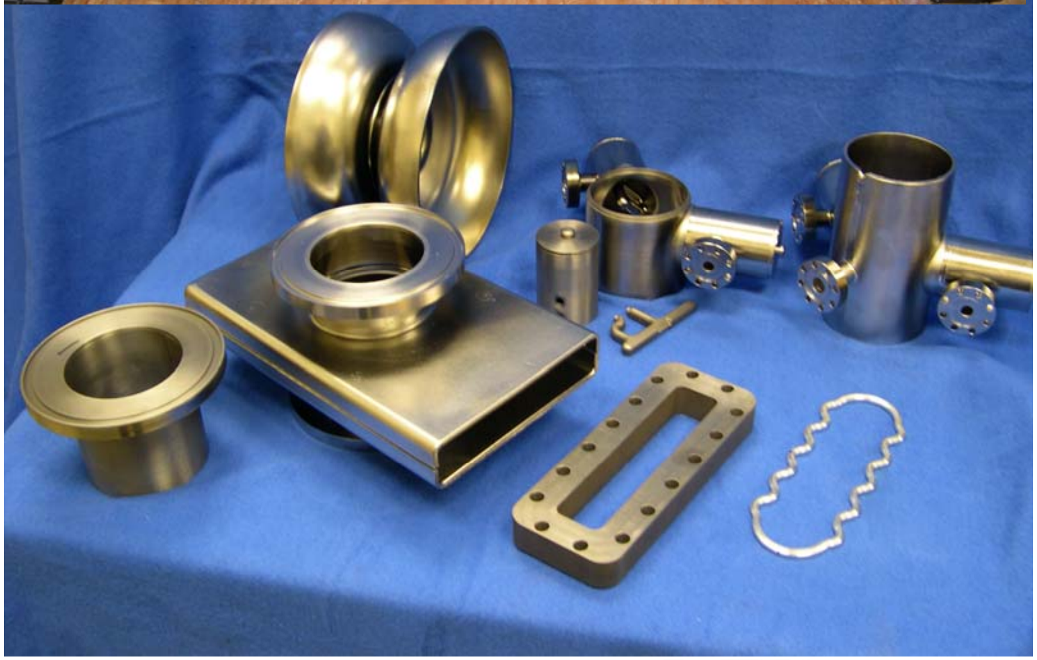
HOM coupler probe/feedthrough

- **JLab single-crystal-sapphire dielectric HOM probe feedthroughs**

JLab licensed the technology to Accel Instruments, GMBH, for commercial exploitation/application

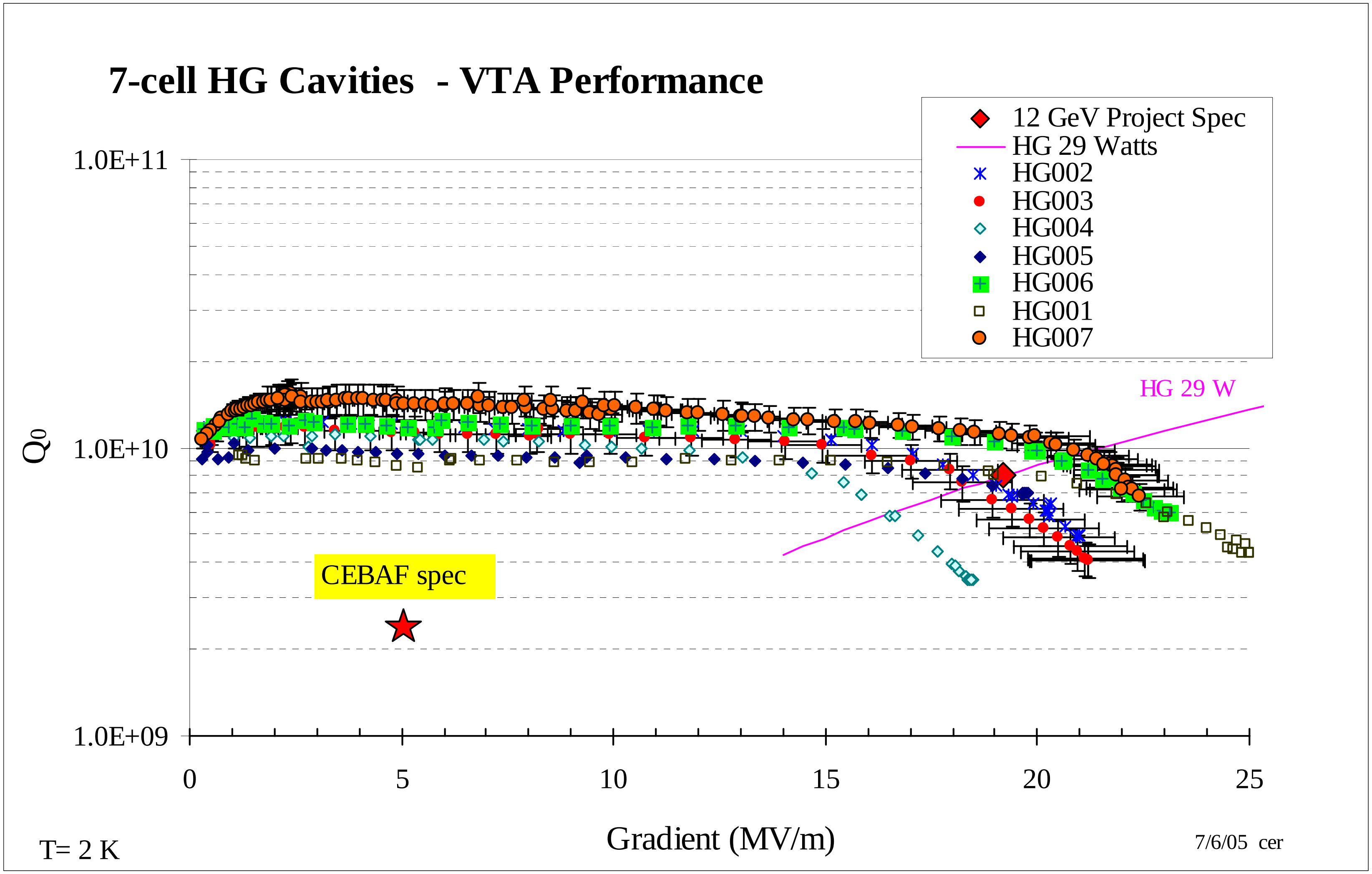
Renascence Cavity Fabrication

- Production set
  - —5 HG and 4 LL 7-cell cavities
  - —RRR 347 Nb
  - —$Nb_{55}Ti$ flanges and helium vessel transition plate
  - —Endgroups on HG and LL are identical
  - —Developed standard production drawings and procedures
  - —Refined assembly sequence details for efficiency and QA
  - —Mix of internal/external shop machining
  - —All in-house chemistry and EBW



Cavity Testing - HG

- **Planned 12 GeV cavity temp:**
  2.07 K
- **Allocated dynamic heat budget:**
  29 W



HG design

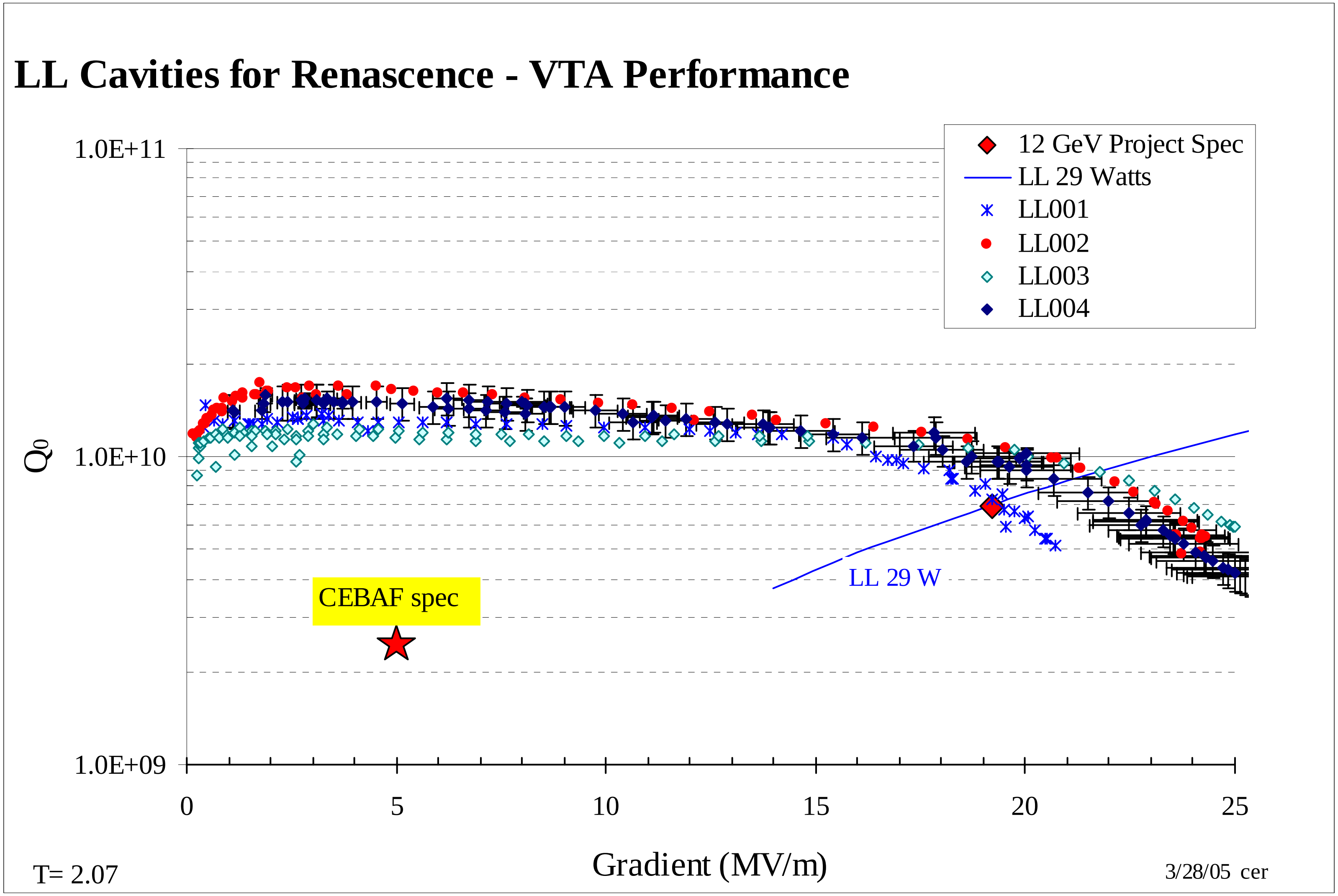
- **No MP encountered**
- **Only HG004 was FE-limited**
- **Q-drop 18-20 MV/m observed without radiation**

Cavity Testing - LL

<u>LL design</u>

- **No MP encountered**
- **No FE-limited cavities**
- **Q-drop 17-21 MV/m observed without radiation**
- **120 C bake improved**

  Q_0 < 15 MV/m only (Input coupler heating suspected)



Microphonics

For lightly beamloaded CW accelerator applications the expense of RF regulation is very significantly influenced by microphonics.

One would like to approach simply matching RF power to the beam with little overhead.

Understanding and controlling microphonics is an important part of system design.

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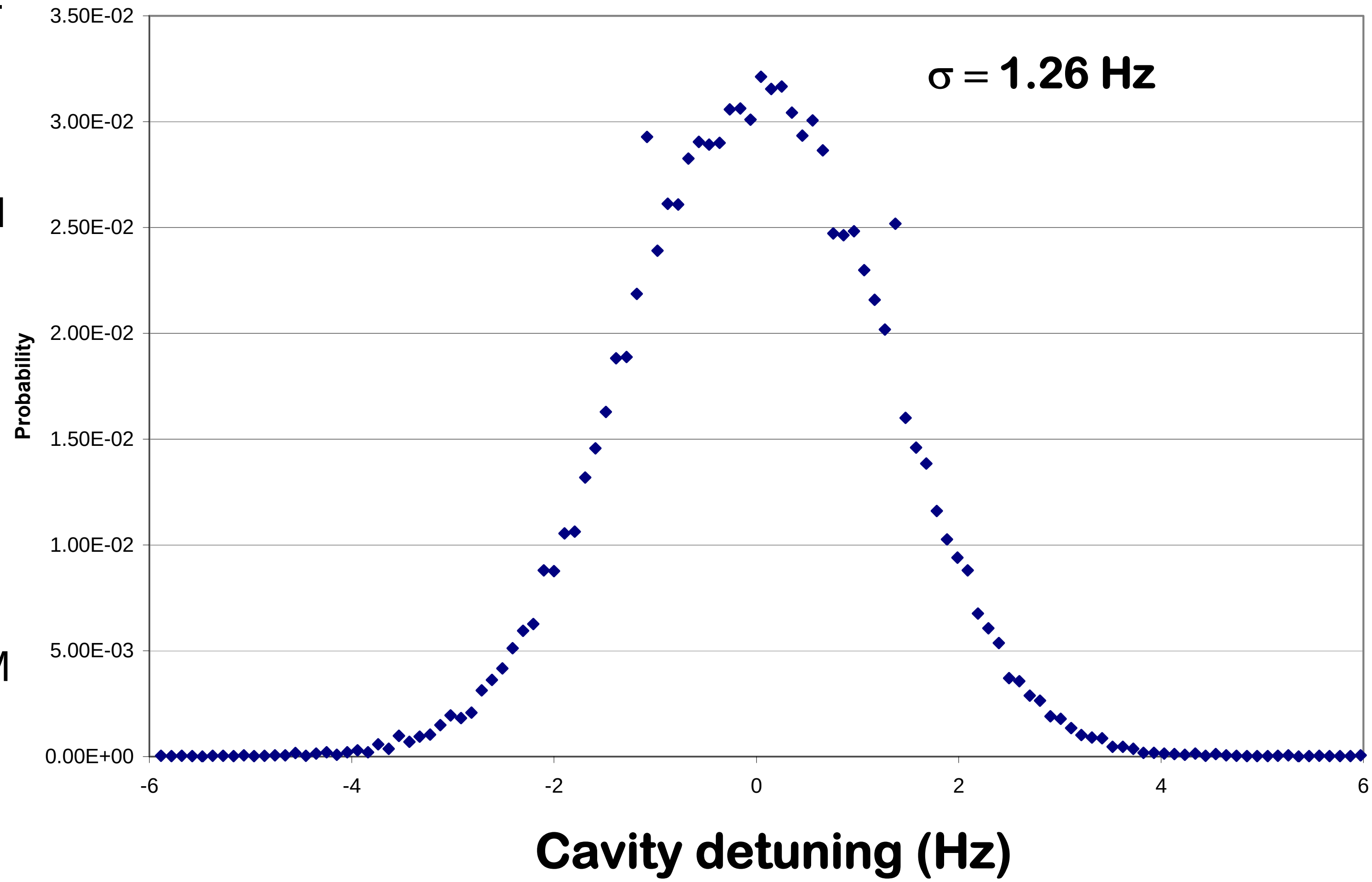
Microphonics

Reduced microphonics

- Elimination of inter-cavity bellows
- Addition of cavity stiffening rings
- Elimination of HOM waveguide elbows
- Suspension from space frame rather than vacuum tank

Microphonic detuning measured to be factor of 3 less in upgrade design CM

Microphonic detuning histogram
Upgrade cryomodule SL21 in CEBAF



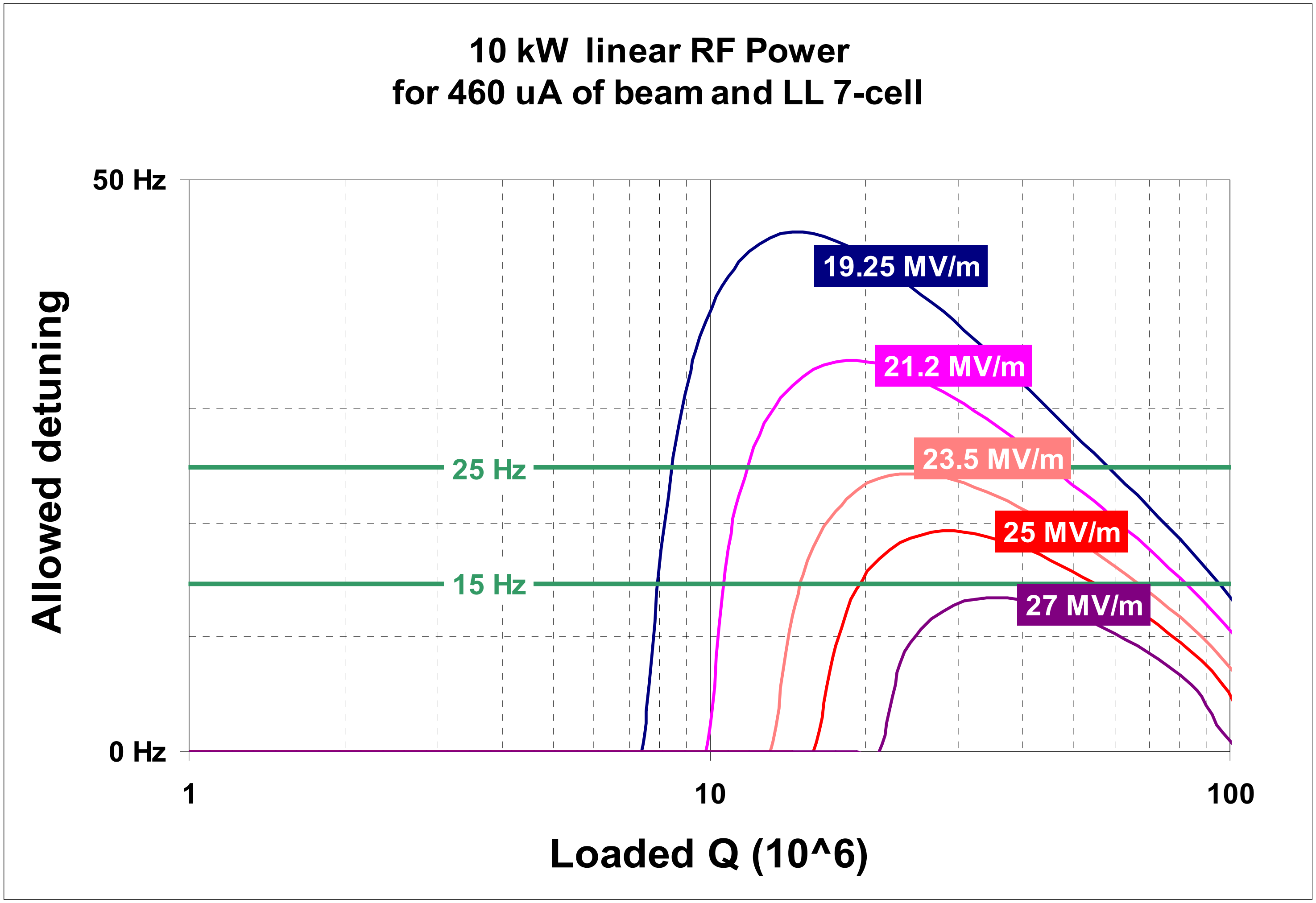
Optimum Matching with Microphonics

Design optimization

— Design choice for input coupling strength (Q_l) depends strongly on microphonics

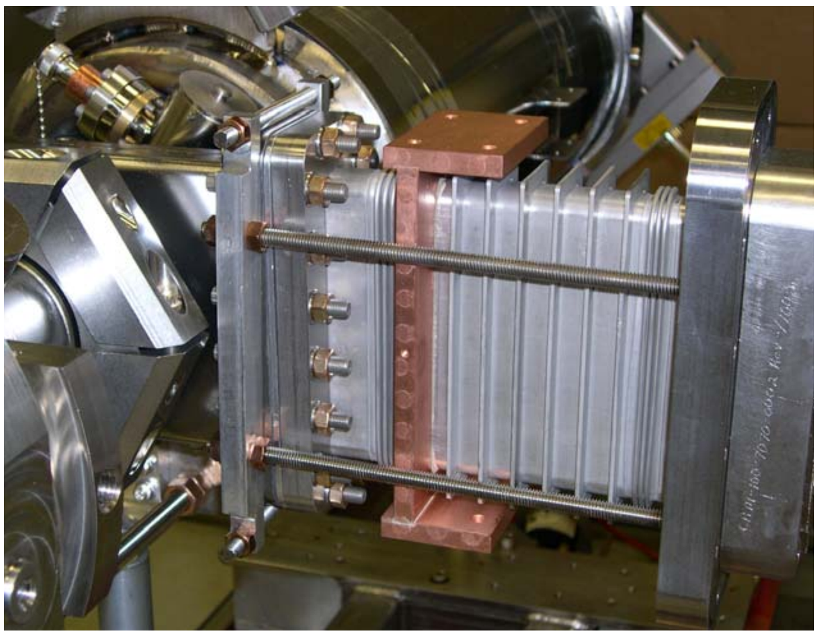
< 15 Hz detuning is credible for the upgrade CM design.

With Q_l of $3.4*10^7 \pm 1.5$ dB, operation to 25 MV/m CW will be possible with 13 kW klystrons.



String Assembly

- Waveguide/window units preassembled and leak checked
- String assembled - one cavity per day
- No issues during assembly



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Transfer of cavity string

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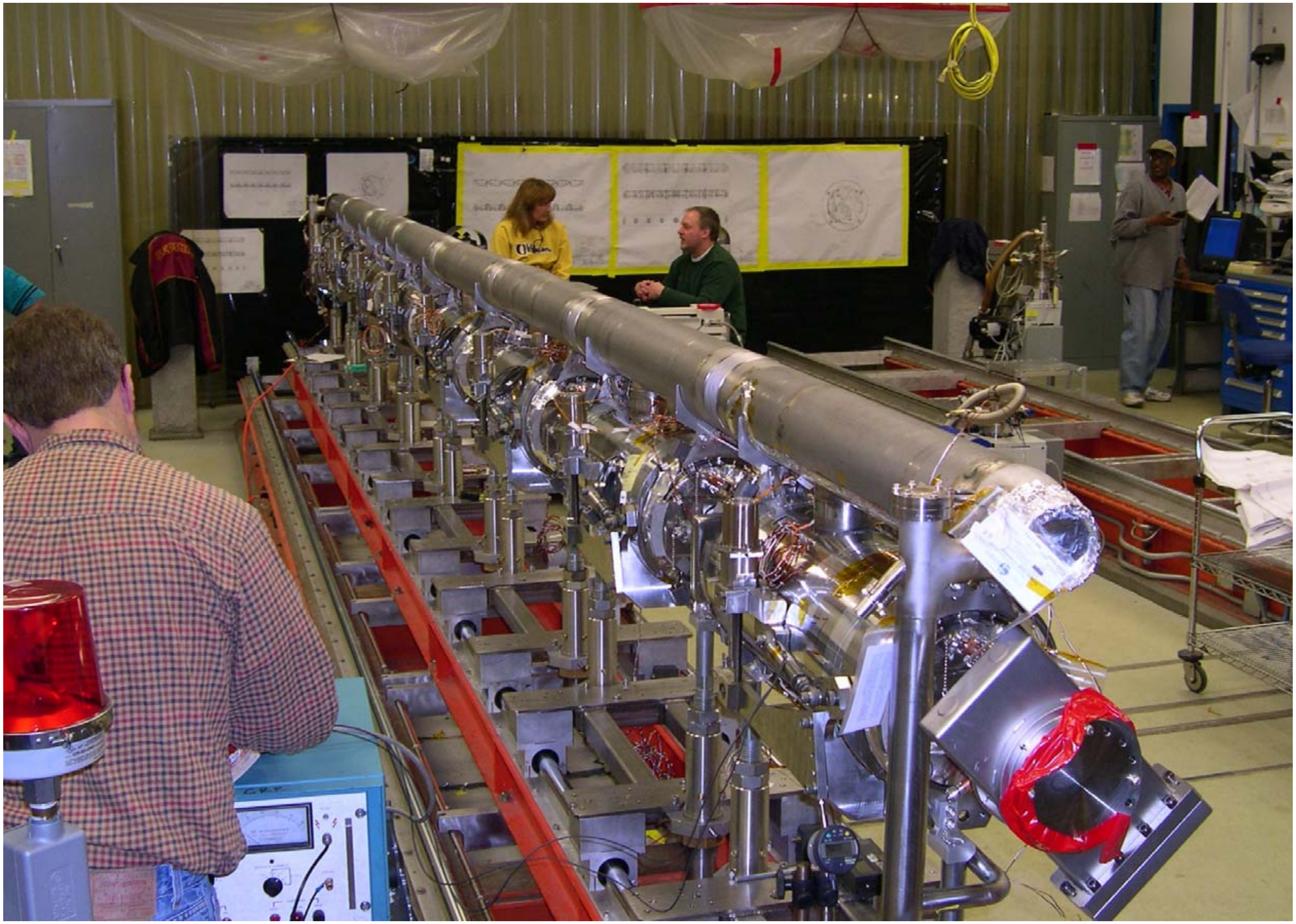
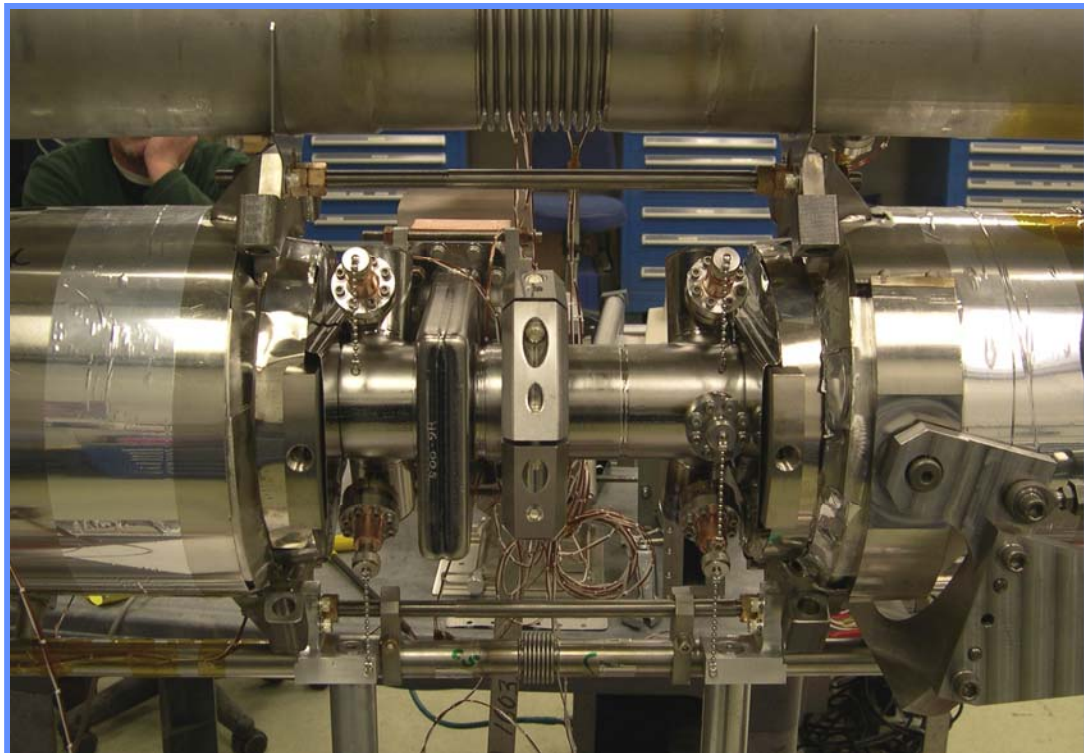
Cryomodule Assembly

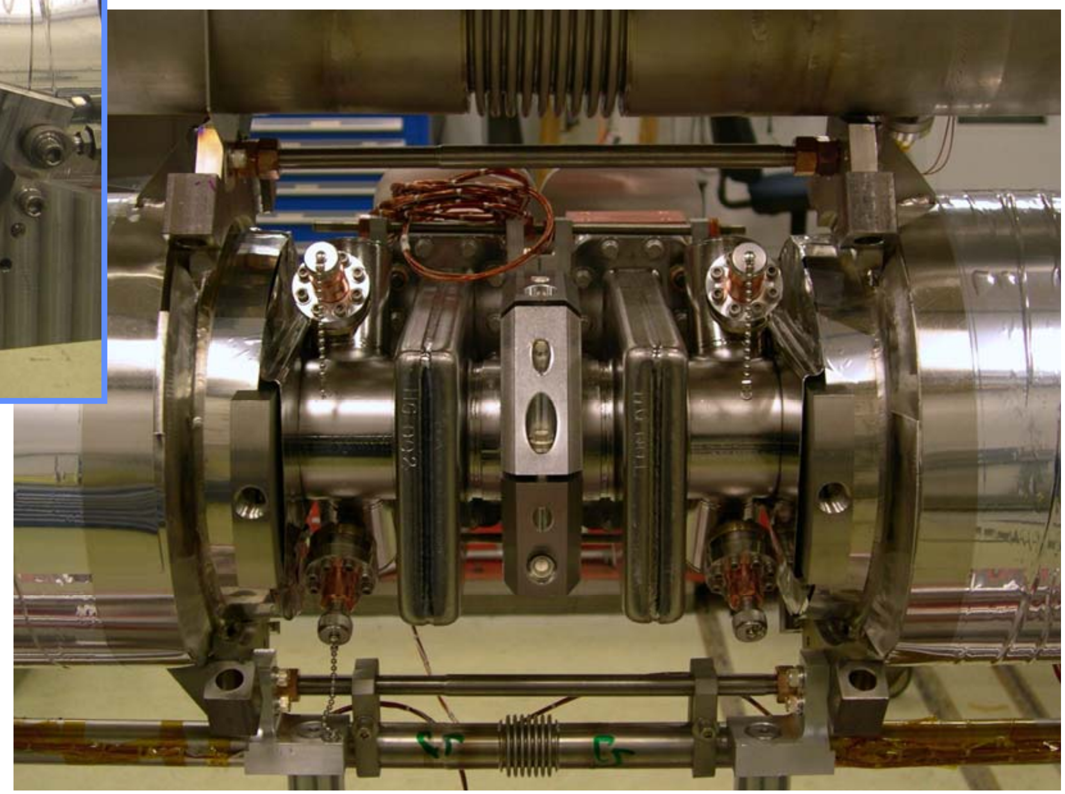


Cryomodule Assembly

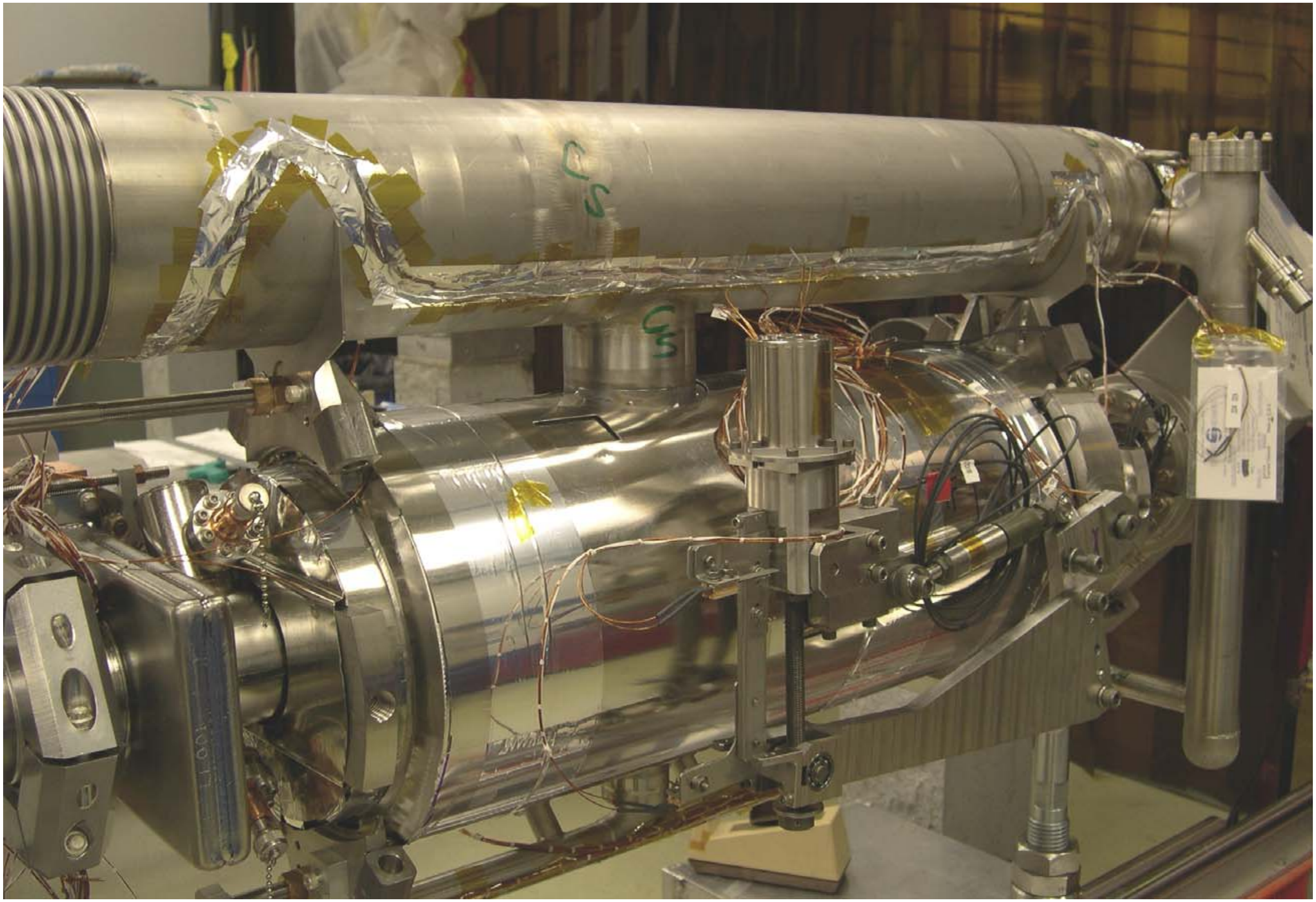


Interface between cavities

Beamline mid-point



Cryomodule Assembly



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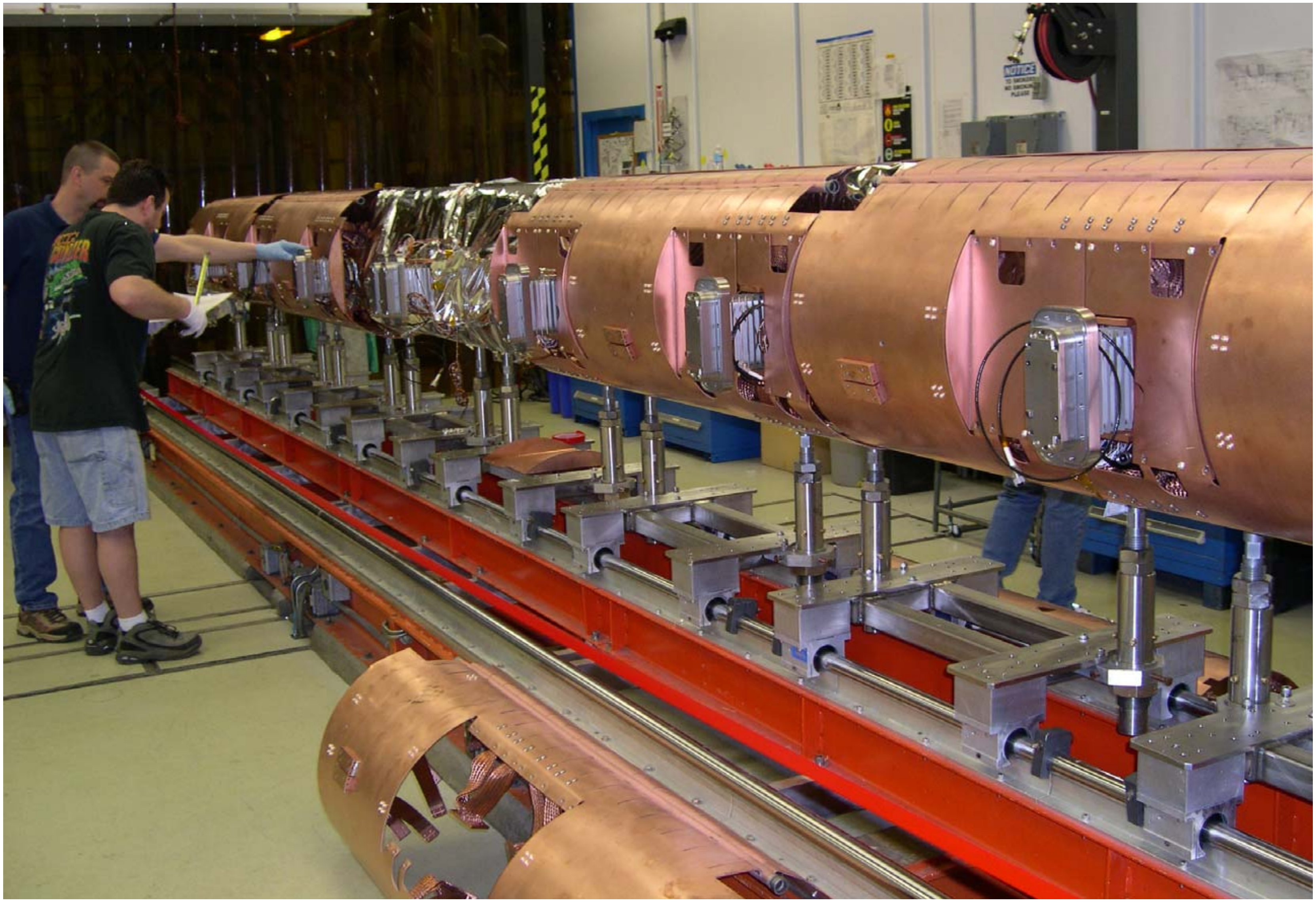
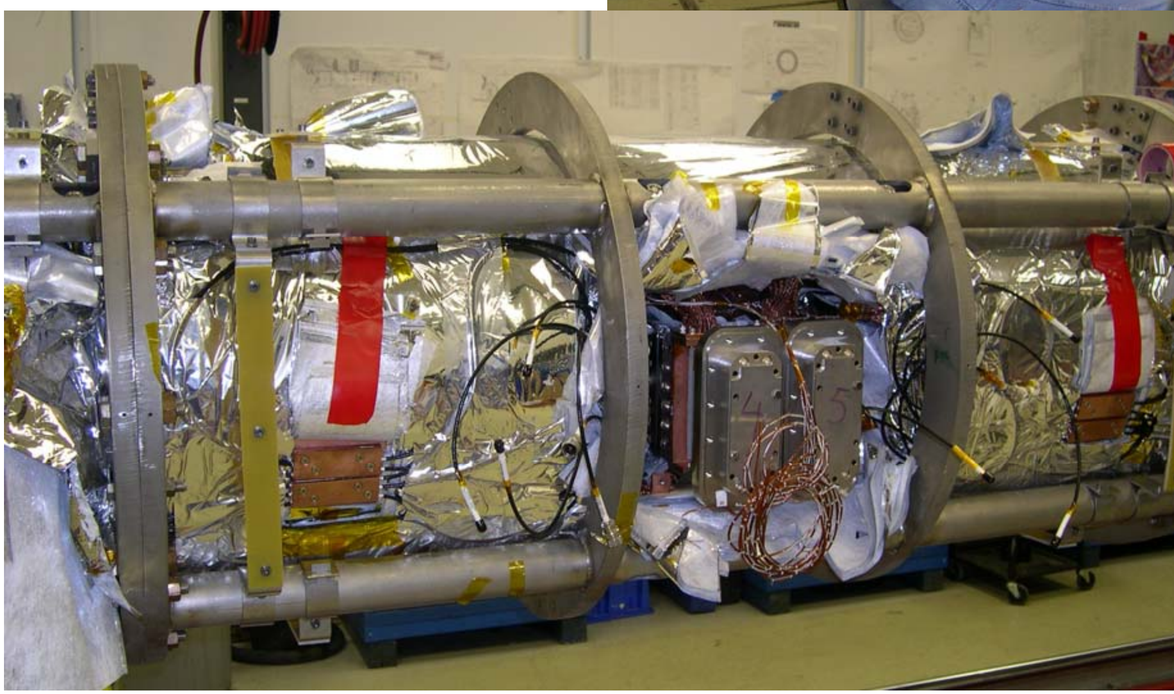


Cryomodule Assembly

Cryomodule Assembly



Cryomodule Assembly

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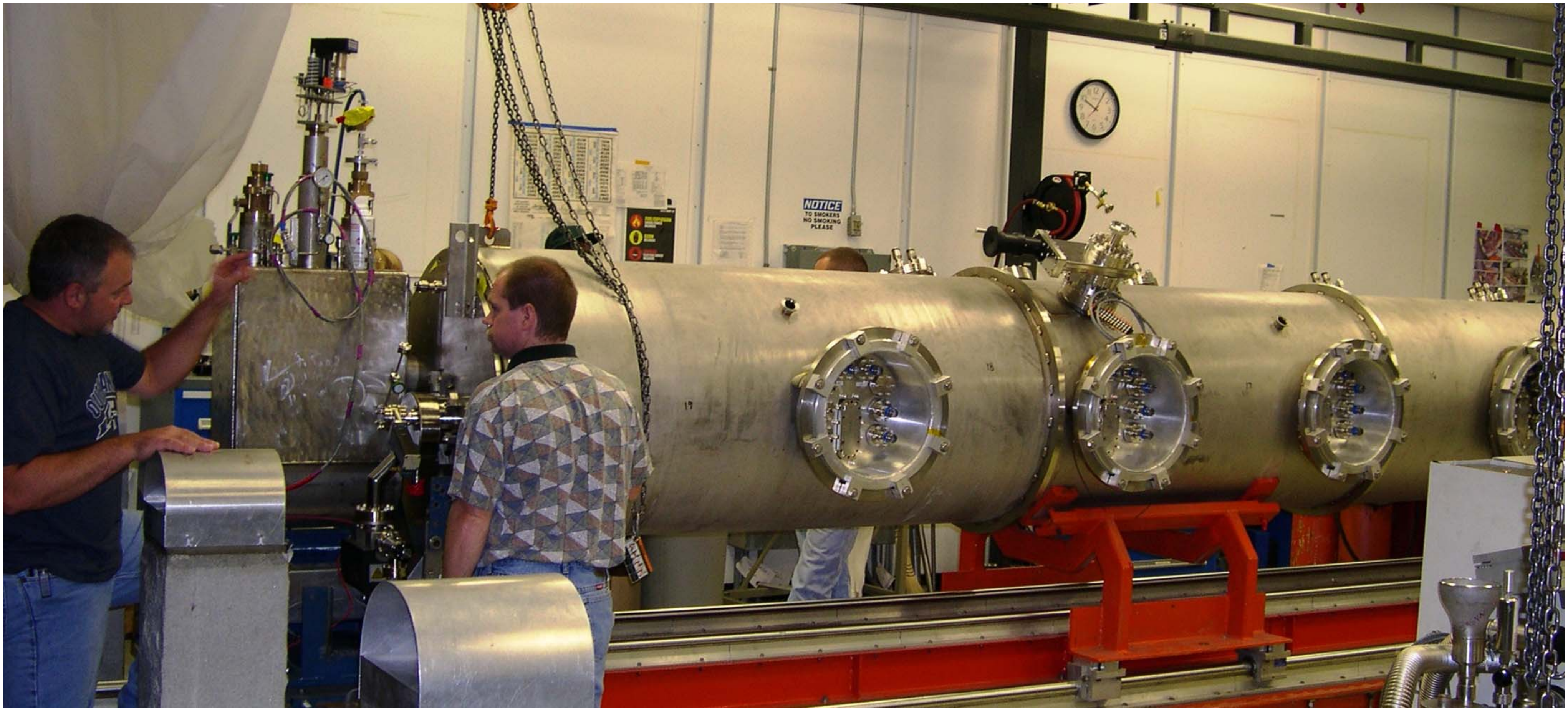

Sealing up vacuum tank July 7, 2005

Plans

- *Renascence* assembly complete this week
- Testing in JLab CMTF (17 kW CW rf available) – 6 week program begins next week
    - Static heat loads – primary and shield
    - Q_e FPC
    - Tuner function – mechanical and piezo
    - Cavity performance – Q_0 vs. E_{acc}
    - Dynamic cryogenic loads – including capacity challenge
    - HOM Q_{ext} each port - polarization analysis, potential count reduction
    - Magnetic shielding effectiveness
    - Microphonic analysis (accelerometers on one cavity)
    - Microphonic compensation test with piezo & prototype LLRF
- Installation and commissioning in September

Summary

- *Renascence*, the final prototype cryomodule for the 12 GeV Upgrade, has built on experience with "SL21", "FEL03", and the SNS production run.
- This latest version includes several design improvements
- Cavity performance spec was met in VTA tests
- Assembly is complete
- Documentation is in good order
- Testing and commissioning now begins
- We anticipate a better-than-100 MV CW cryomodule

25 MV/m x 0.7 m x 8 cavities = 140 MV, with 275 W @ 2 K

A credible goal !

Acknowledgements

- Cryomodule design
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