Status of the Cornell ERL Injector Cryomodule

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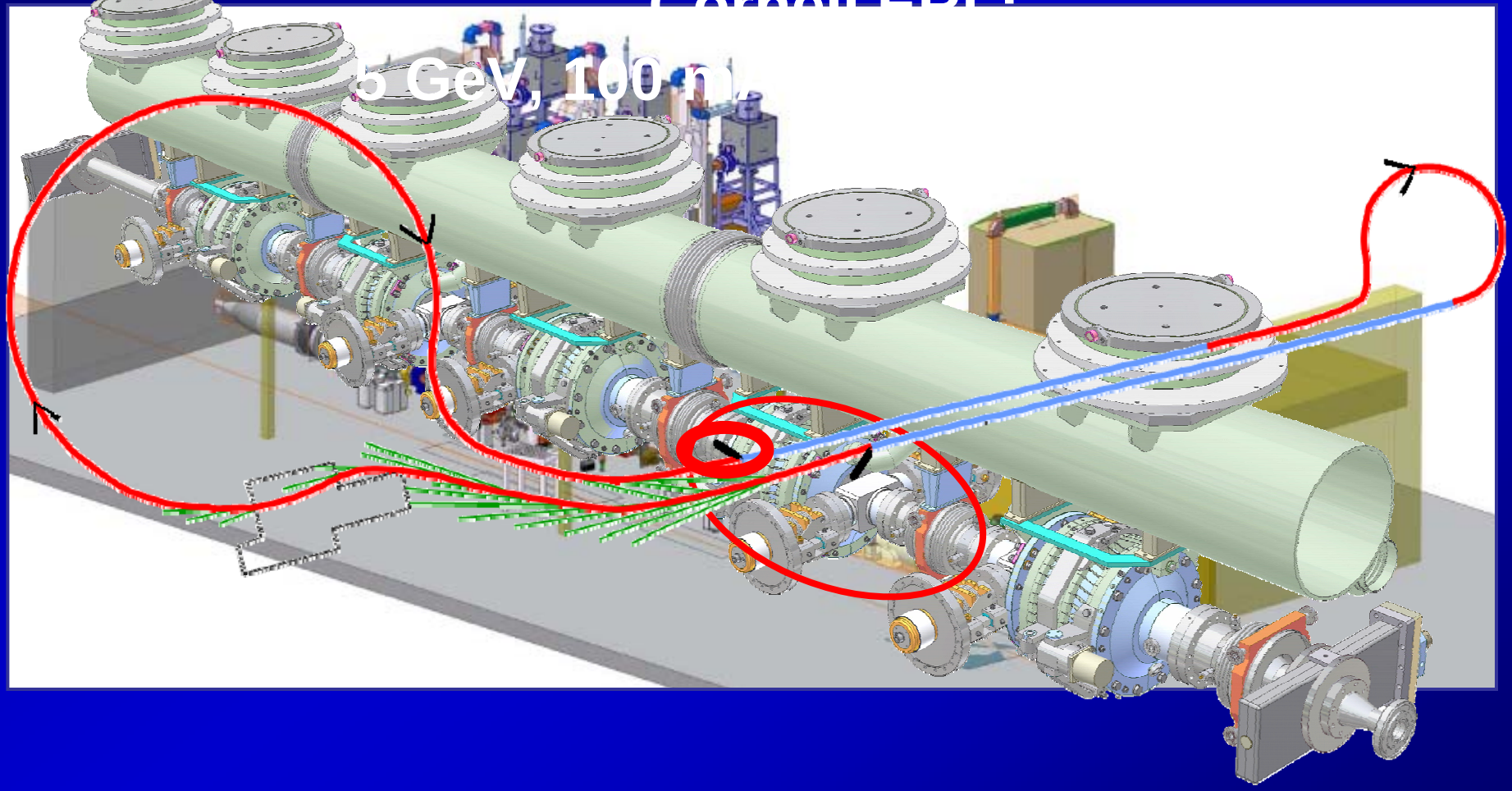
A 100 mA SRF Injector Cryomodule for the Cornell ERL X-ray Light Source



Injector Cryomodule Design

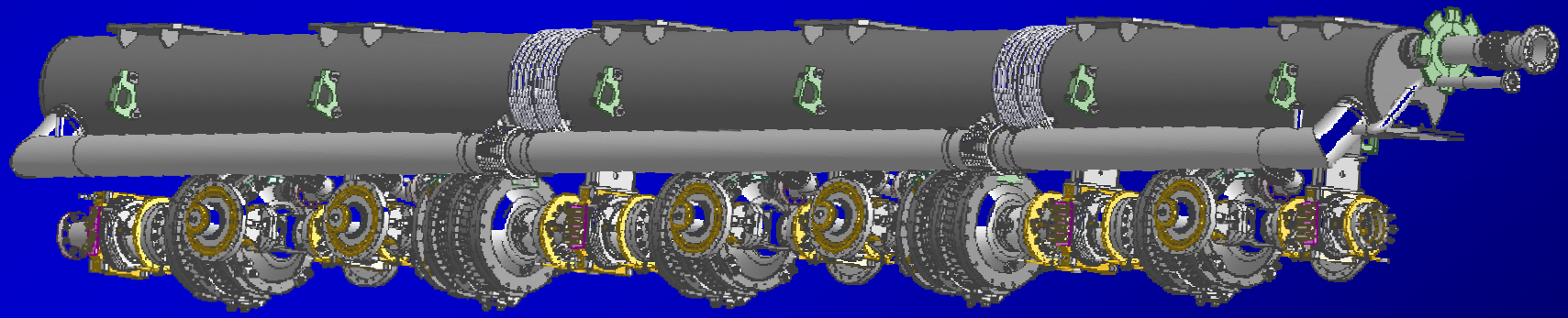
ERL Injector Beam Requirements

- **Energy gain: 5 to 15 MeV**
- **High cw current:**
  - **100 mA (77 pC/bunch) @ 5MV, 0.5 MW, ε=1 mm-mrad**
  - **33 mA (26 pC/bunch) @ 15MV, 0.5 MW, ε=0.1 mm-mrad**
- **High beam power ≤ 0.5 MW**
- **Short bunch length: 0.6 mm (2 ps)**
- **Very low emittance ε_n = 0.1-1 mm-mrad**

⇒ Well beyond present state-of-the-art!

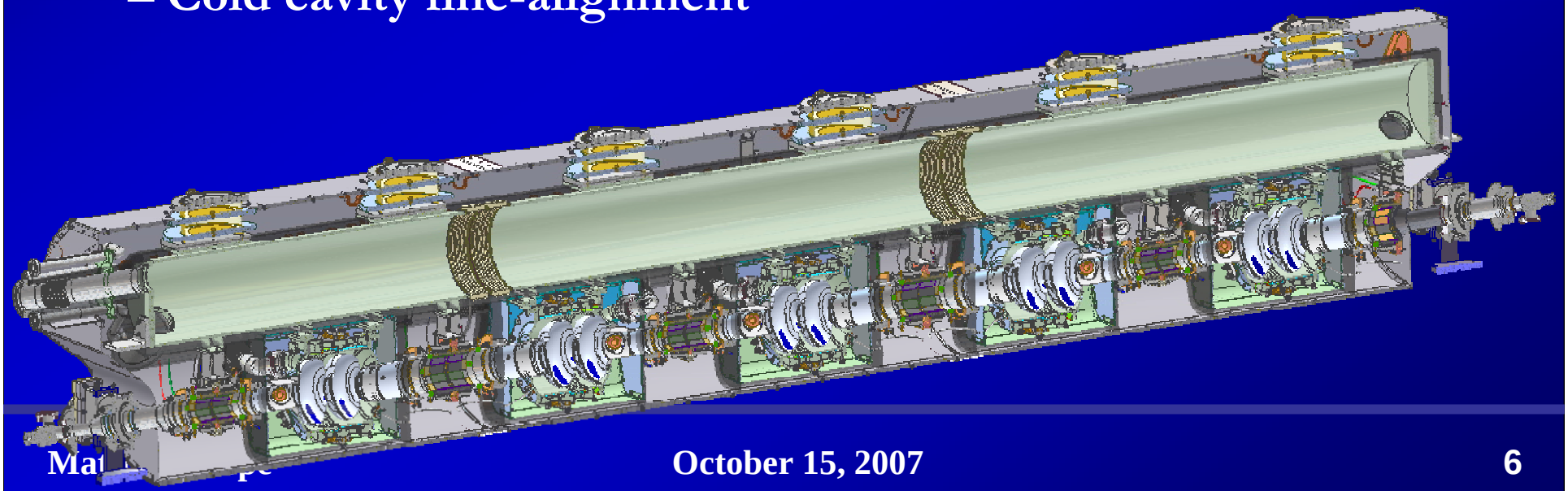
ERL Injector SRF Answers (I)

- **1.3 GHz SRF 2-cell cavities:**
  - 5–15 MV/m (1-3 MV) to each deliver 100 kW power to beam
  - 5 cavities for 5 -15 MeV energy gain
  - Number of cells limited by max. input coupler power
- **RF system:**
  - Two 50 kW input couplers per cavity for 100 kW total
  - One 120 kW cw klystron per cavity (coupler pair)



ERL Injector SRF Answers (II)

- **Beamline HOM Loads for aggressive damping of HOM's generated by high current and short bunches**
- **Symmetric beam line for beam emittance preservation:**
  - **Twin coax input couplers**
  - **Round beam line absorbers (no HOM loop couplers)**
  - **Cold cavity fine-alignment**



Design Philosophy

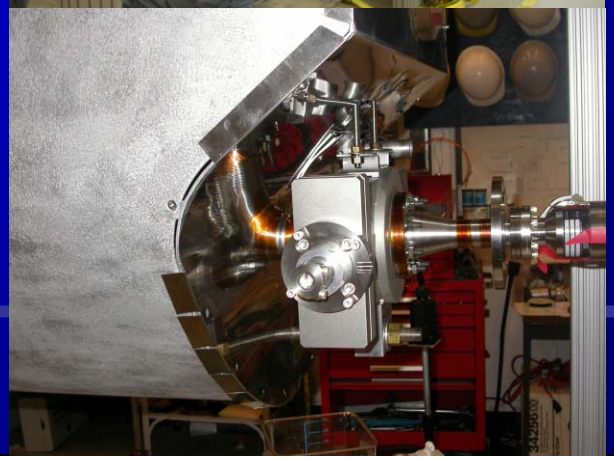
- Use similar cryomodule concept in ERL injector and main linac.
- Cryomodule concept based on the well established TTF technology to reduce risk and minimize development time
  - Cavities supported by large diameter Helium-gas return pipe (HGRP)
- Significant modifications for ERL specific needs:
  - Necessary modifications (for high cryo-loads, …)
  - Innovations
- Simplify and reduce cost

ERL Injector Cryomodule Design

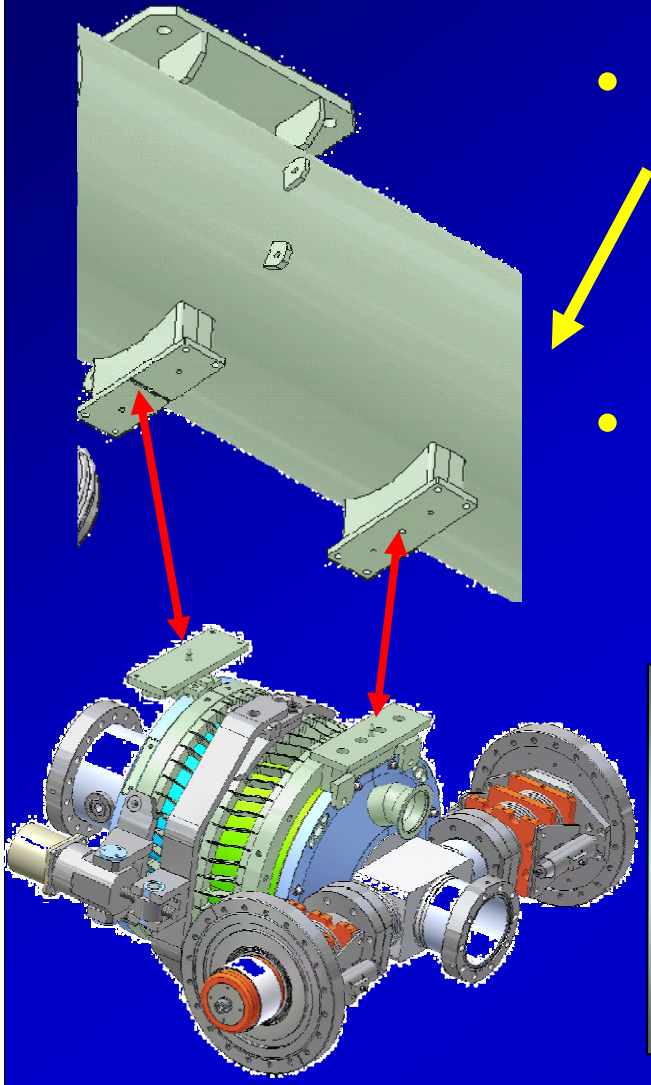
- Changes compared to a TTF cryomodule:
  - Increased diameter of 2-phase 2K He pipe to 10 cm for high 2K load in CW cavity operation
  - Ti HGRP for lower thermal contraction during cool-down
  - Direct gas cooling of chosen 5K and 80K intercept points (input couplers, HOM loads) with He-gas flow through small heat exchangers to intercept significant 5 K and 80 K loads
  - HOM absorbers between cavities
  - Improved magnetic shielding for very high Qo, 3 layers
  - No 5K shield, only a 5K cooling manifold
  - New end-cap and feed-cap concept with reduced length

ERL Injector Innovations (I)

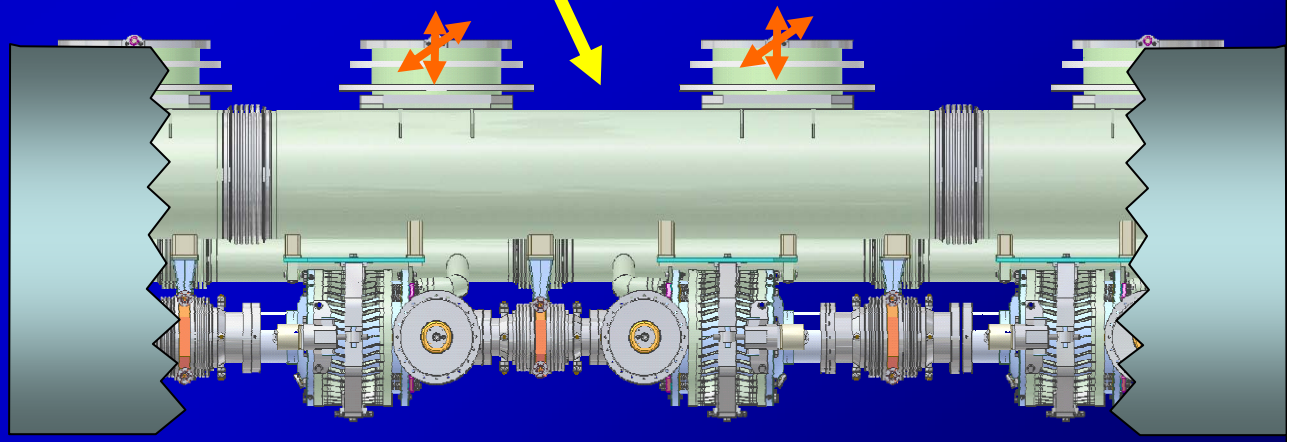
- Tuner stepper easily replaceable while string is in cryomodule
- Rail system for cold mass insertion into Vacuum Vessel
- WPM with simple electronics
- In-situ bake for cold and warm couplers, no further atmosphere exposure, no pre-conditioning
- Gatevalve inside of module with outside drive



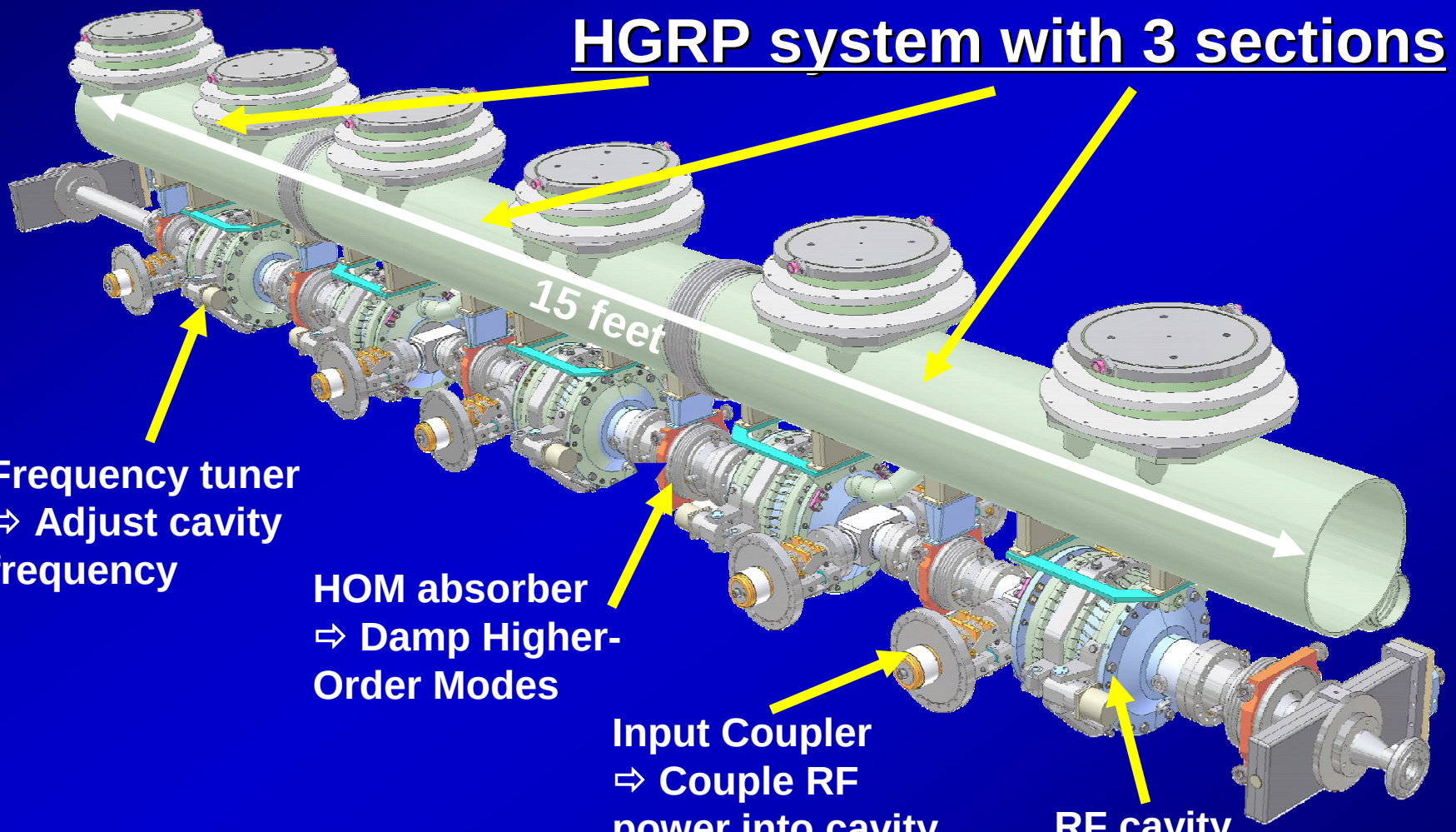
ERL Injector Innovations (II)



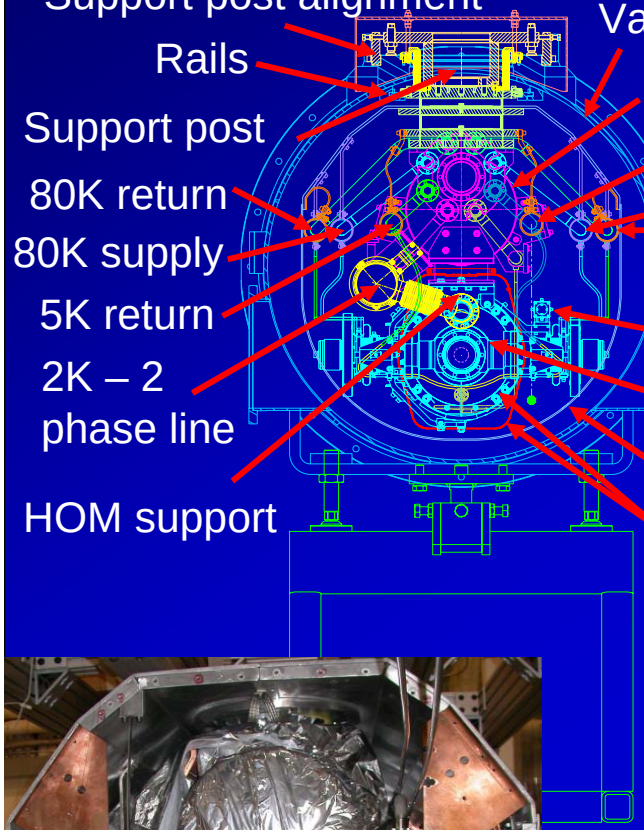
- Precision fixed surfaces between the beamline components and the HGRP ⇒ easy "self" alignment
- Cavity-subunits can be fine-aligned while cavities are at 2K (if required)

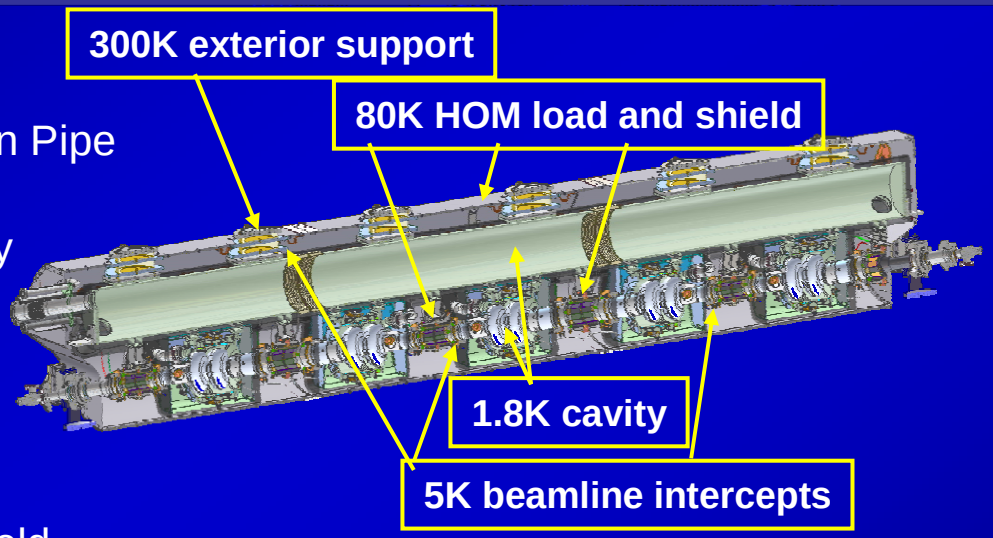


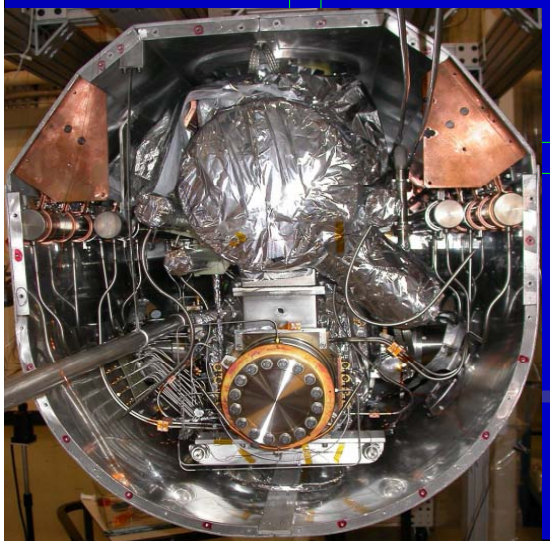
The ERL Injector Cryomodule

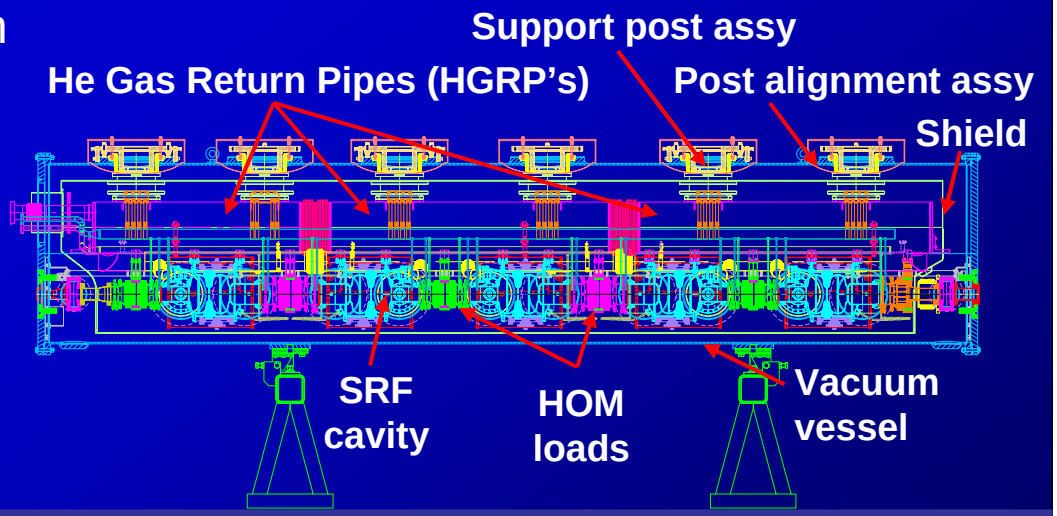


ERL Injector Components









The Beam Line Components:

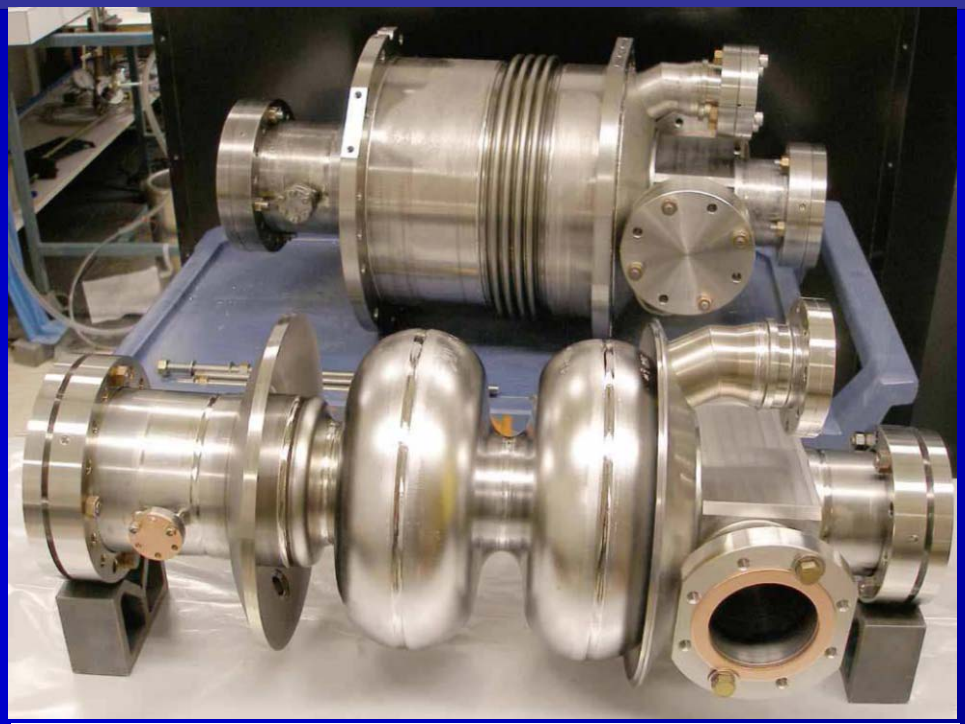
Design, Fabrication and Test

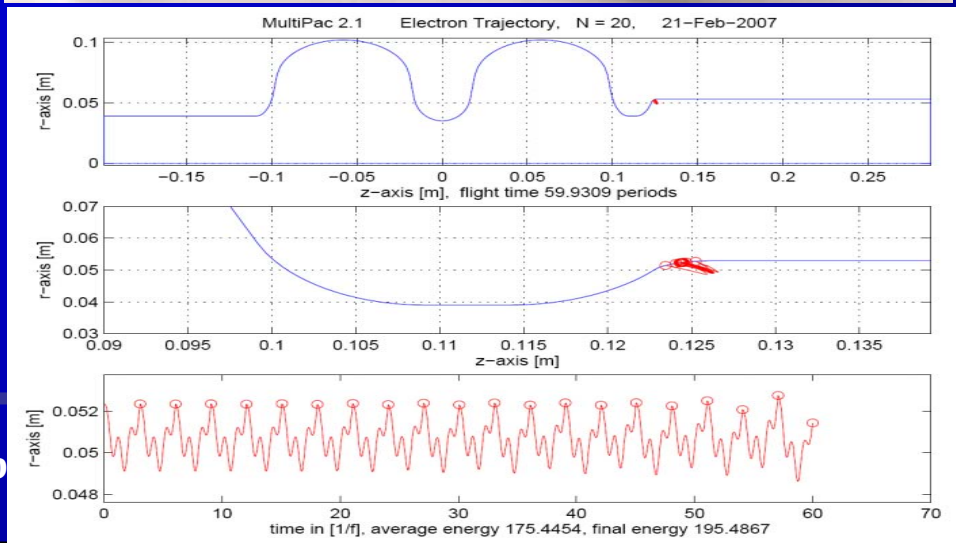
- Cavity
- Input coupler
- HOM dampers
- Tuner

Superconducting 1.3 GHz 2-cell Cavities

- Brazed conflat flanges
- Twin-input coupler
- Ti He vessel
- Mild multipactor at large beam tube transition, very easily processed in vertical tests

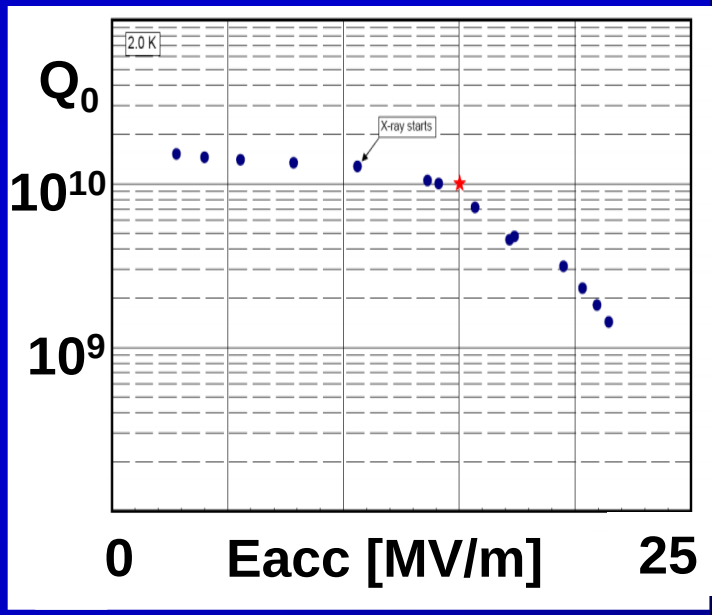
Frequency	1300 MHz
R/Q	222 Ω
Gradient	5-15 MV/m
Q_{ext}	$4.6 \cdot 10^4$ – $4.1 \cdot 10^5$

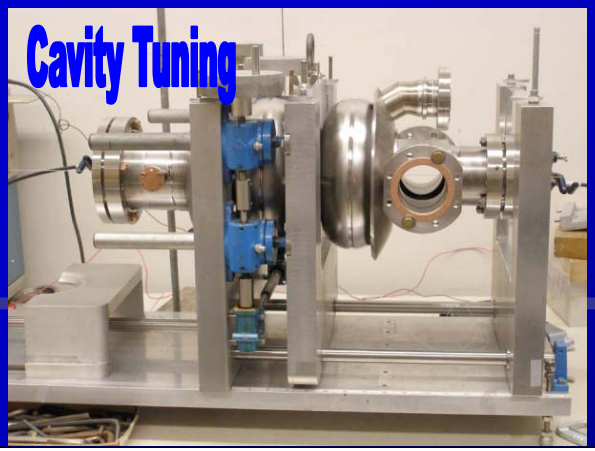




2-cell Cavities : Vertical Test

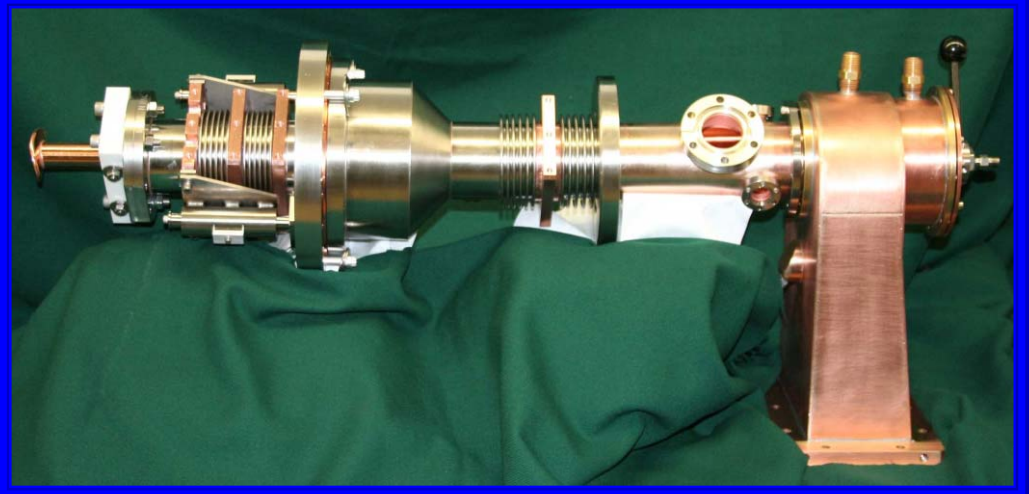
- Only BCP, no 800C
- 6 cavities fabricated and tested in house
- All cavities meet 15 MV/m spec
- Two tested for H disease, no H disease

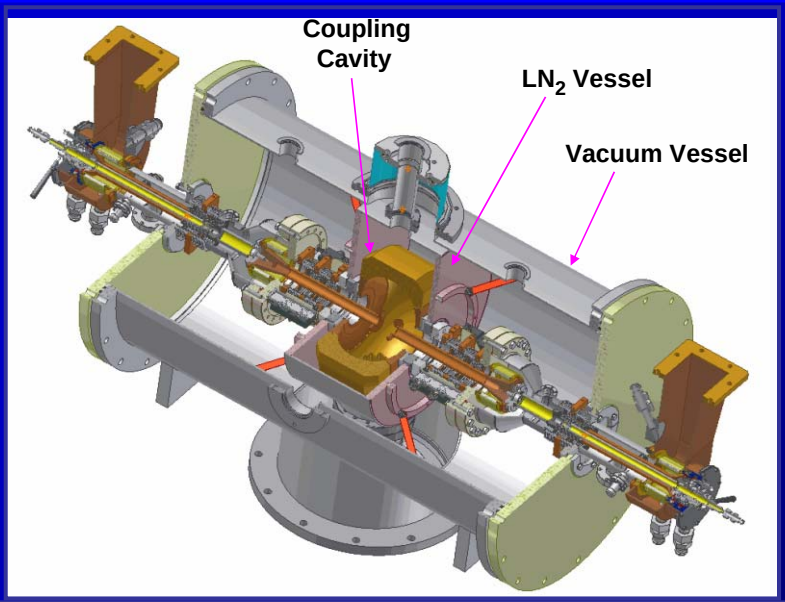




Coaxial Input Couplers

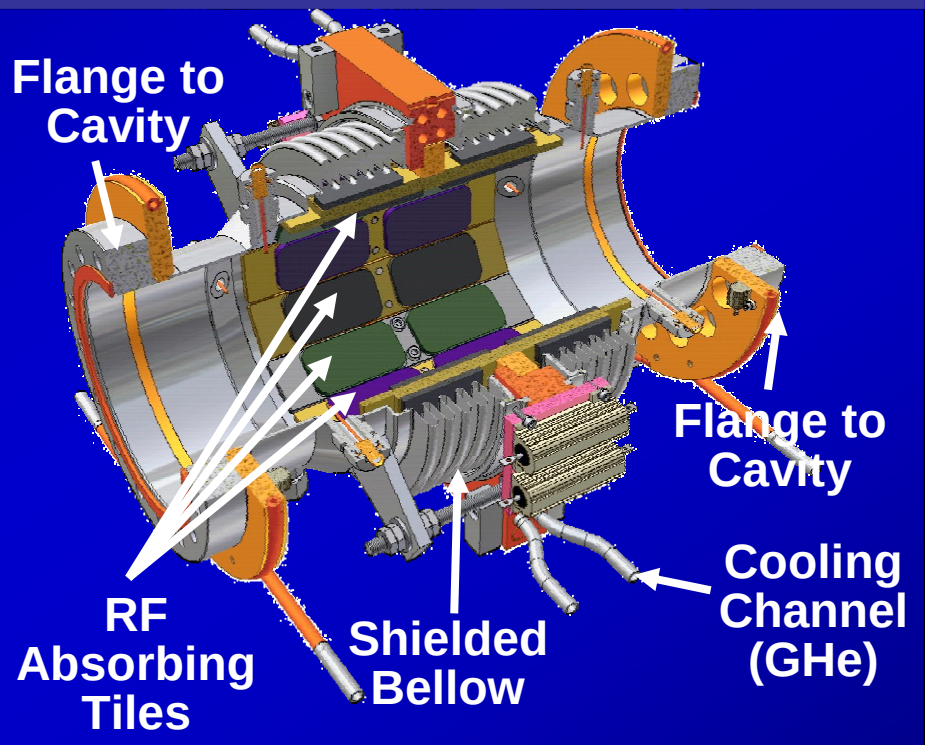
- Design for high cw power > 50 kW
- 2 prototypes tested up to 50 kW cw, 80 kW pulsed
- Production couplers with improved cooling are presently under fabrication; first two tested very successfully



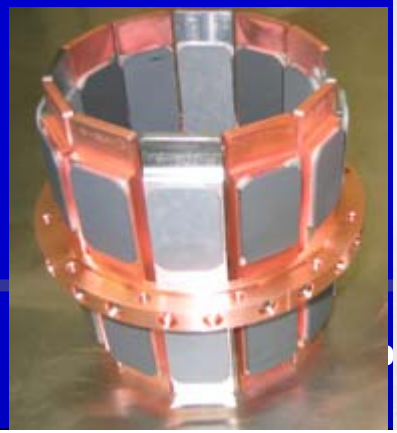


Beam Line HOM Loads

Power per load	26 W (200 W max)
HOM frequencies	1.4 – 100 GHz
Operating temp.	80 K
Coolant	He Gas
RF absorbing tiles	TT2, Co2Z, Ceralloy

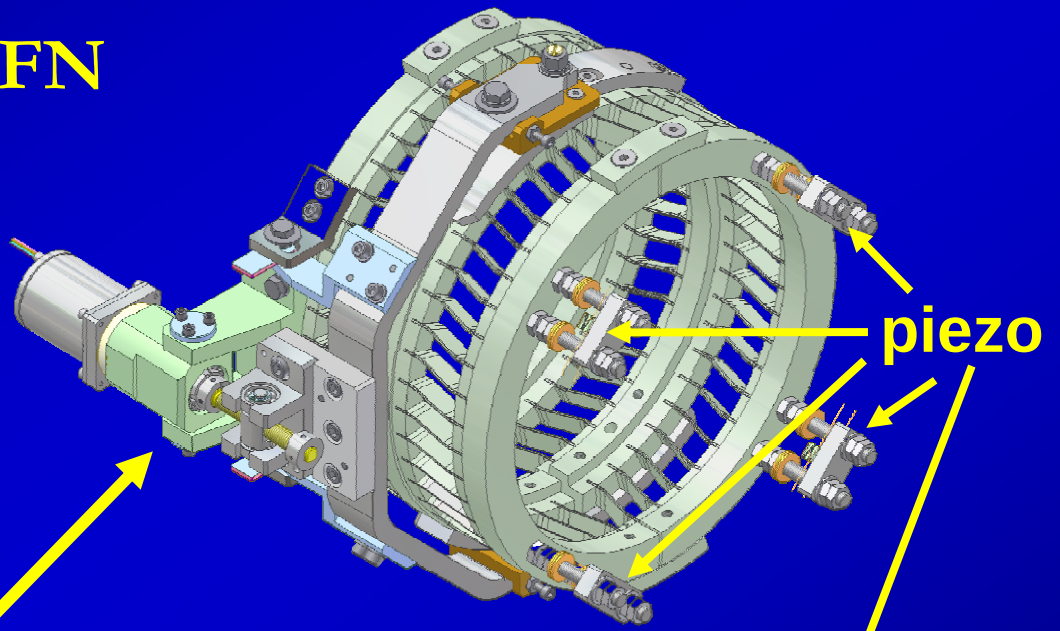


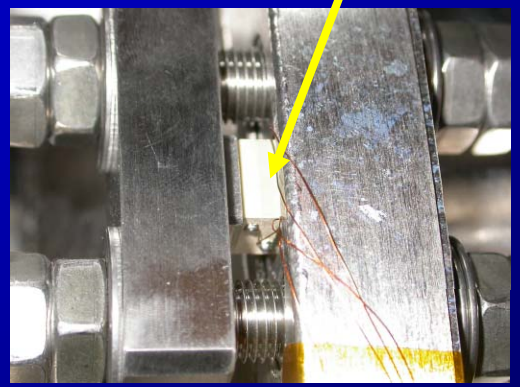
- 2 proto-types fab'ed by Cornell
- 6 production loads fab'ed by industry

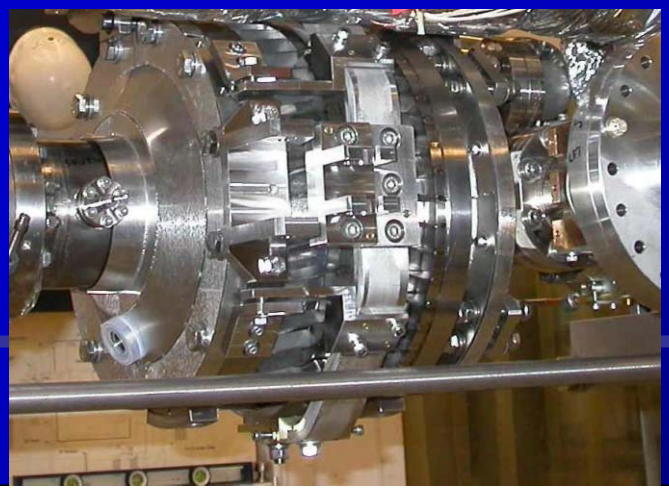


Frequency Tuners

- Modification of the INFN blade tuner
- Added piezos for microphonics compensation (R&D)
- Stepper motor easily replaceable while cavity string is in cryomodule
- 6 units fabricated by industry



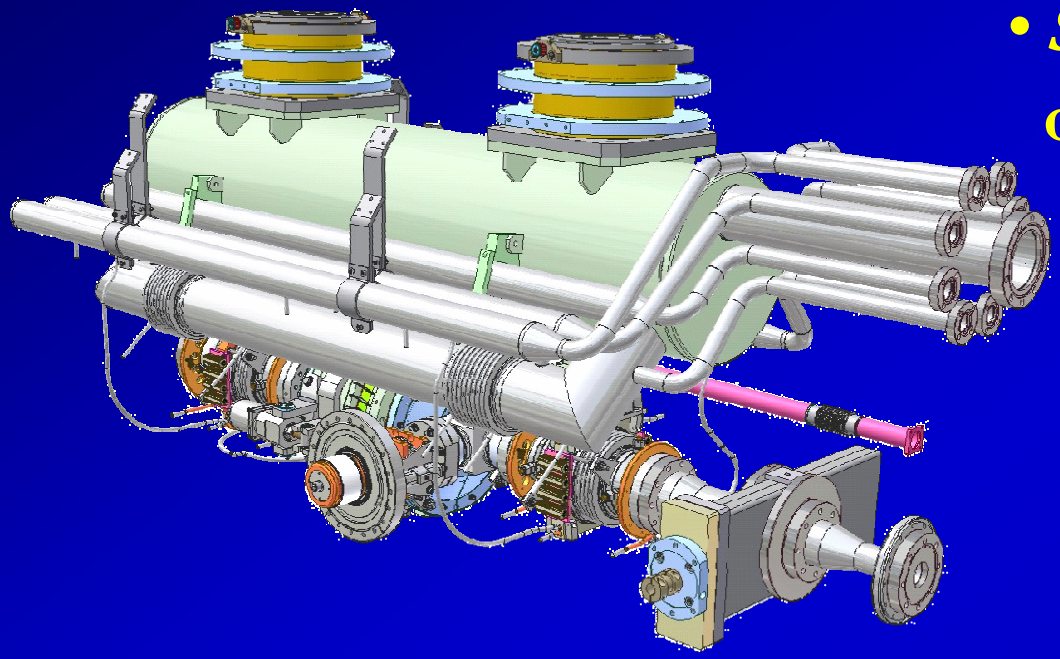




Along the Way:

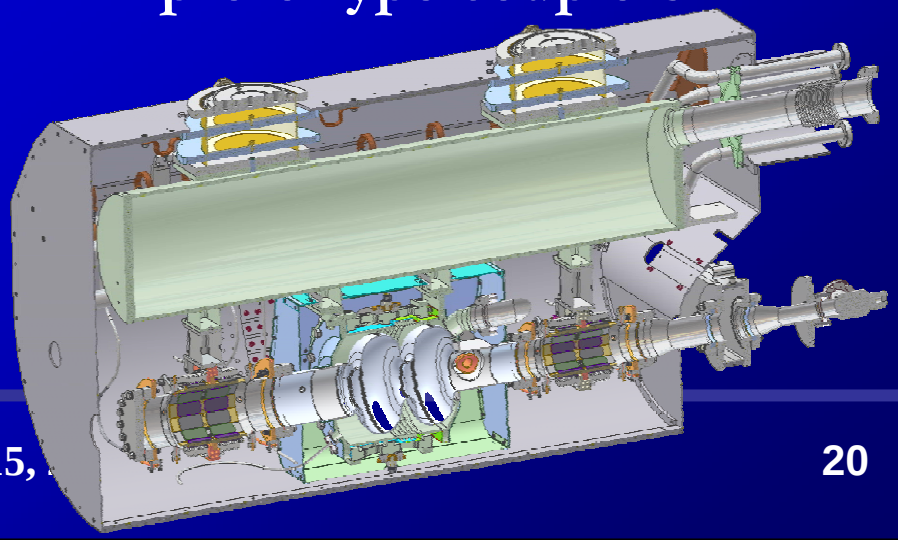
The Horizontal Test Cryomodule (HTC)

Along the Way: The Test Cryomodule

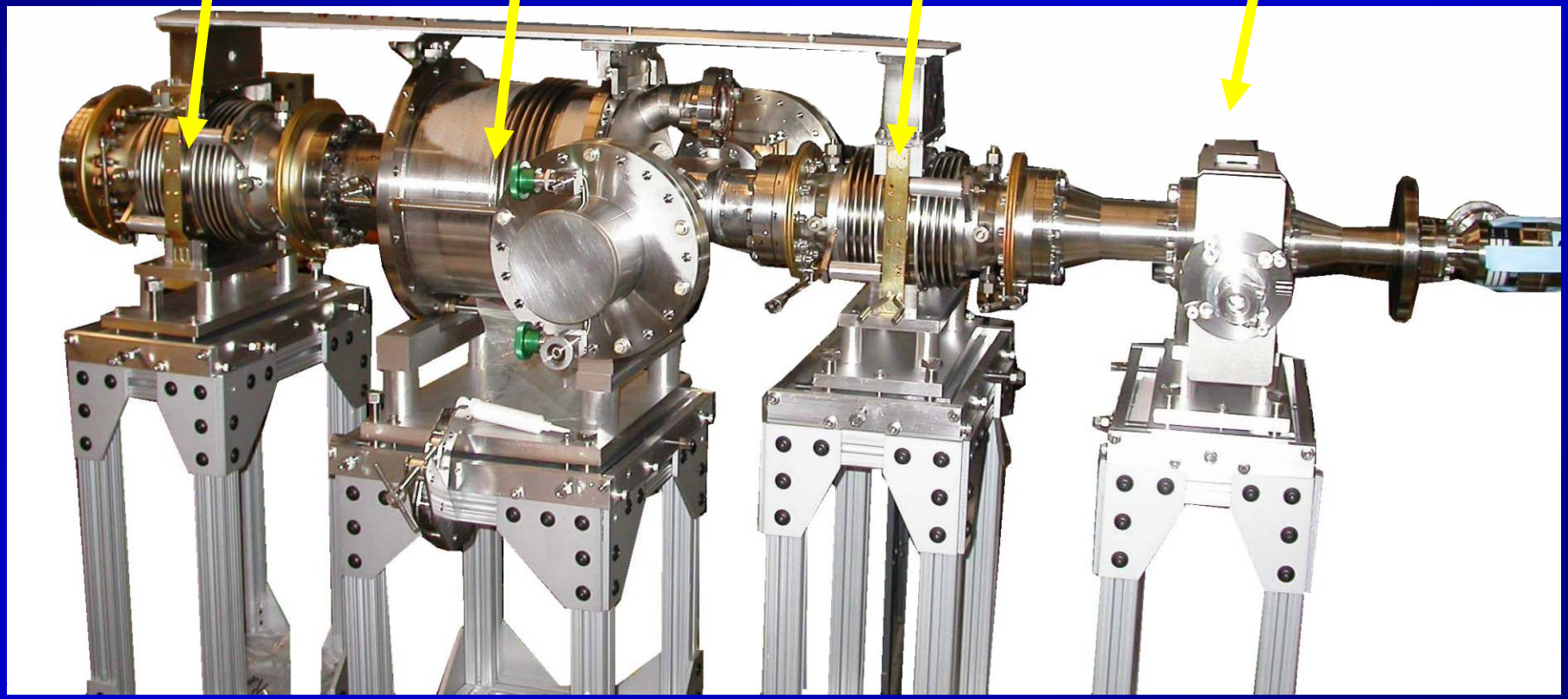


- *Single* cavity test version of full injector module
  - Same concept,…
  - … just shorter
  - spare 2-cell cavity
  - spare tuner
  - proto-type HOM loads
  - proto-type couplers

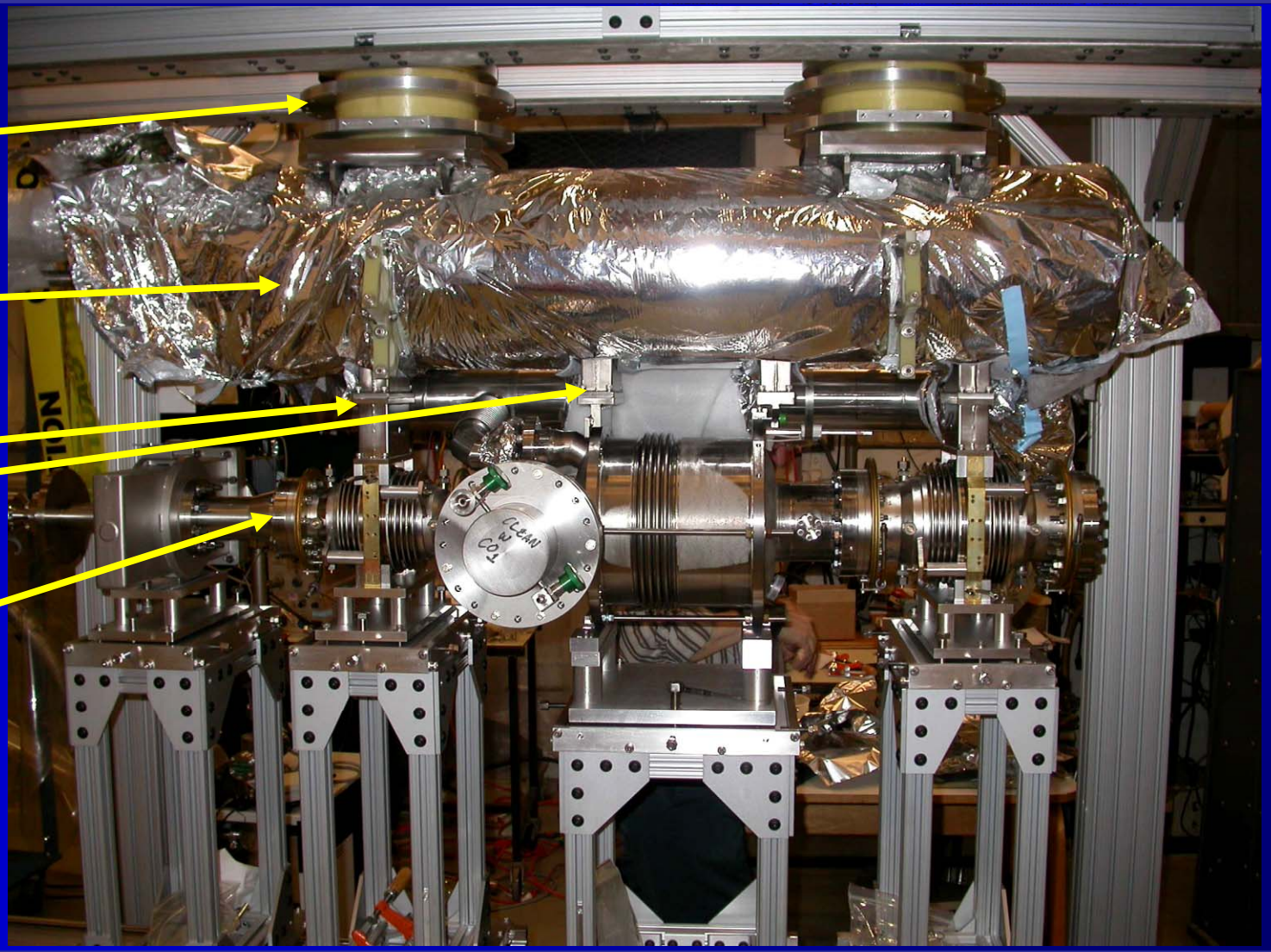
- Vacuum vessel will be used later as an ERL main linac cavity test cryomodule



Beam Line for Test Module



Test Cryomodule Assembly



120C Cavity and Coupler Bake (cold part)

In-situ bake for cold and warm couplers, no further atmosphere exposure, no pre-conditioning

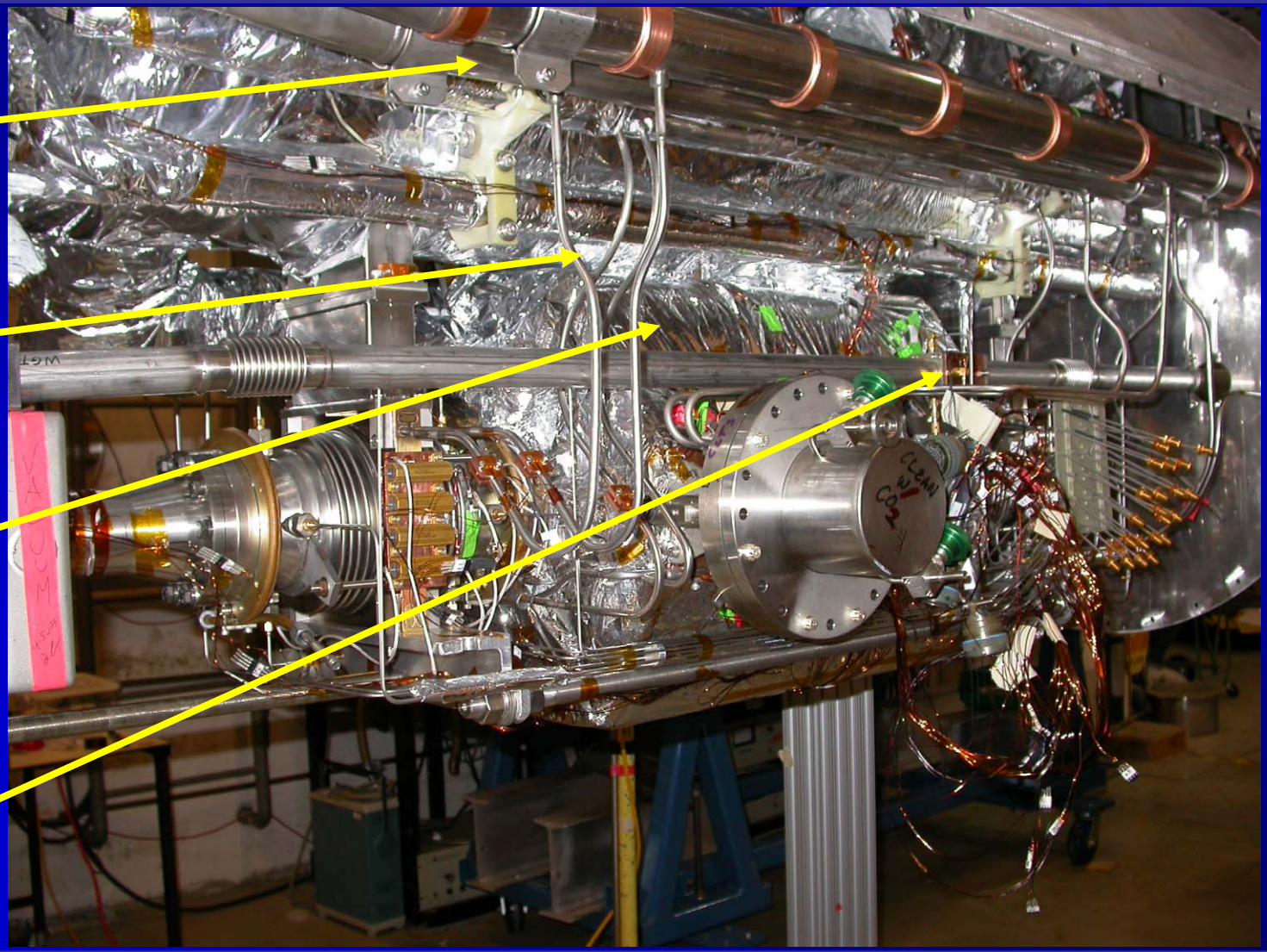
Add 5K and 80K Cryogenic Pipes, Wire Position Monitor, Magnetic Shield II, Cables, …

5K and 80K supply / return pipes

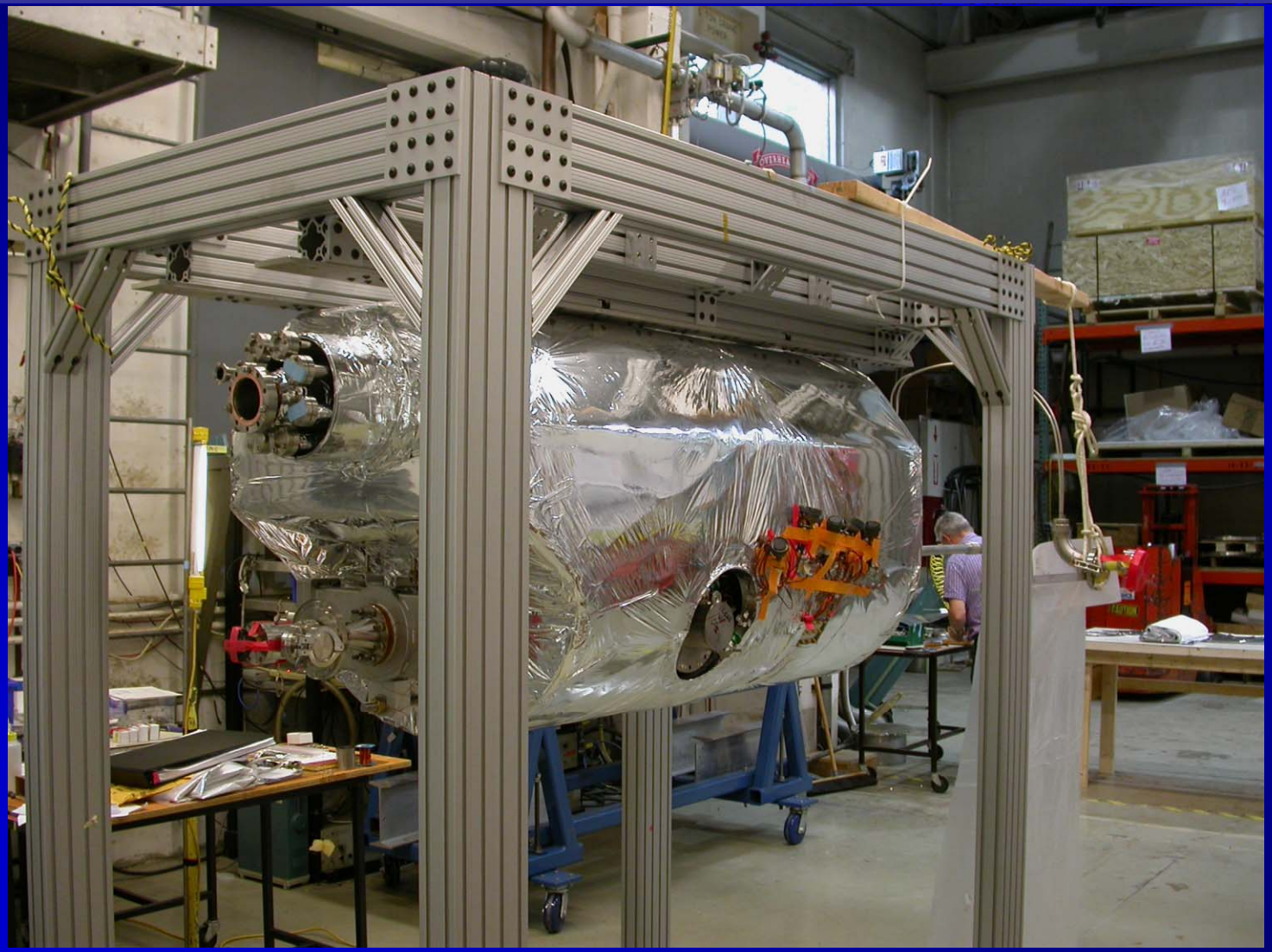
¼" cryogen distribution tubes

Second magnetic shield around cavity

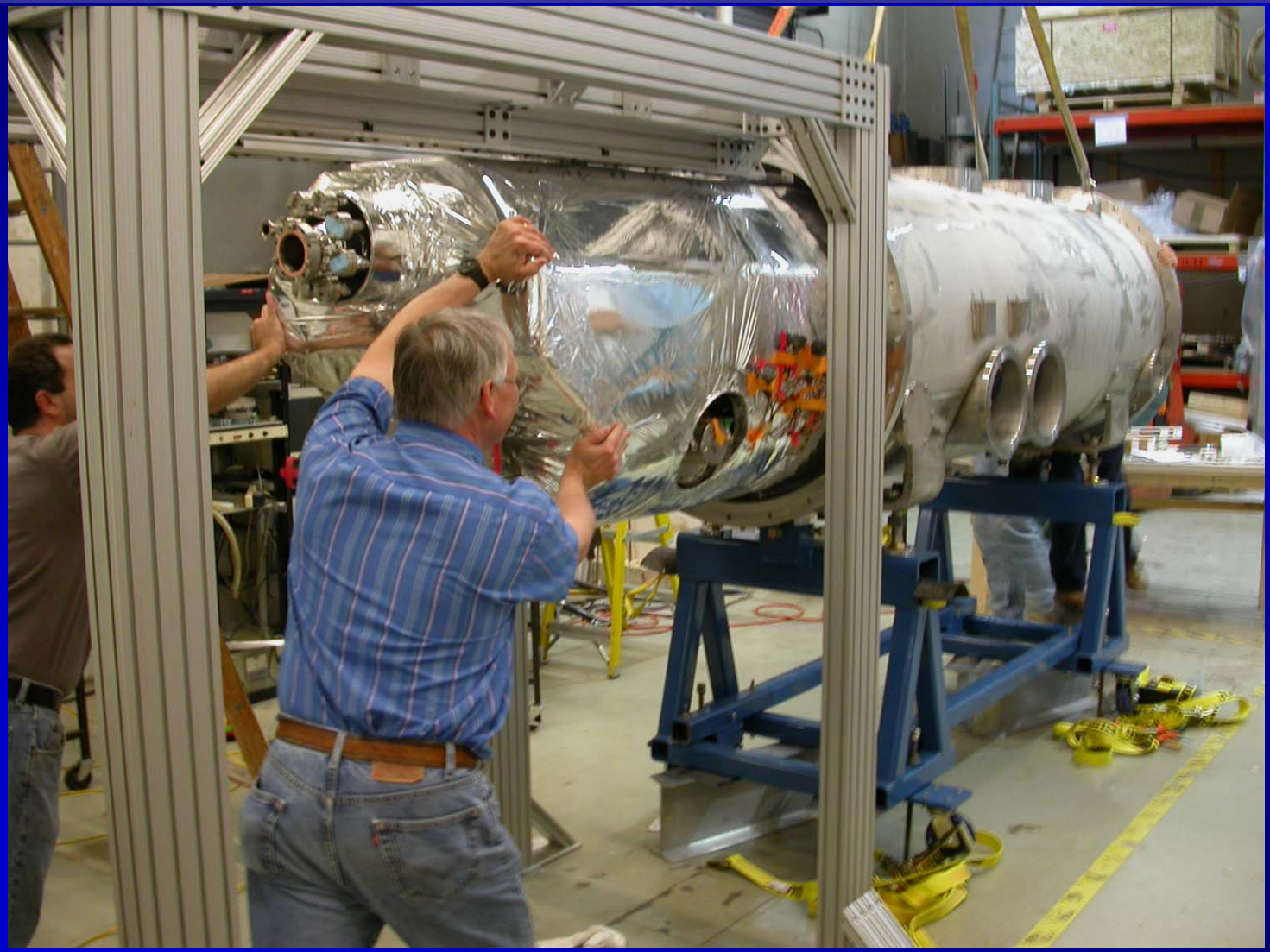
Wire position monitor block mounted to cavity



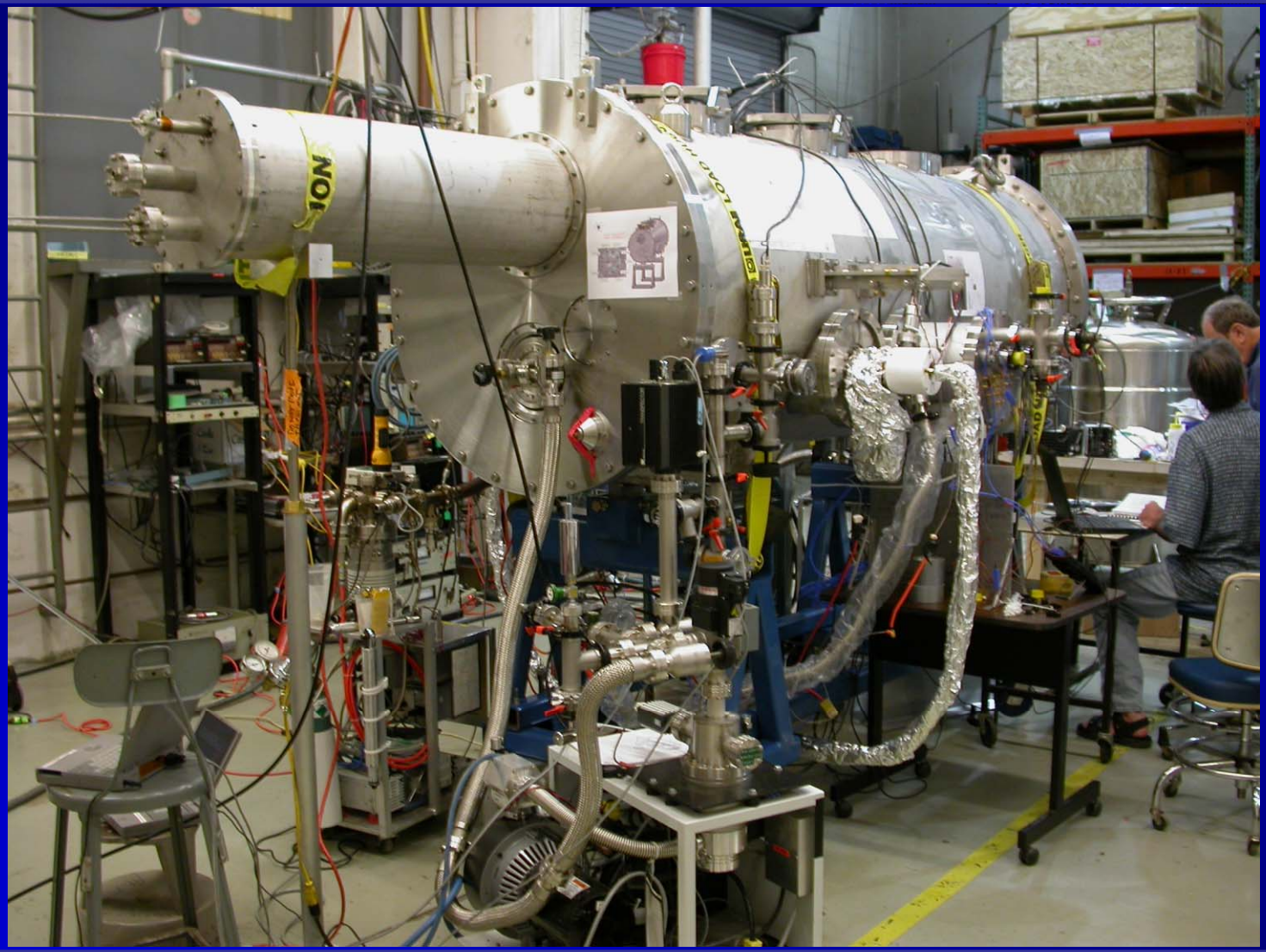
80 K Shield, magnetic shield, MLI



Slide Cold-Mass into Vacuum Vessel



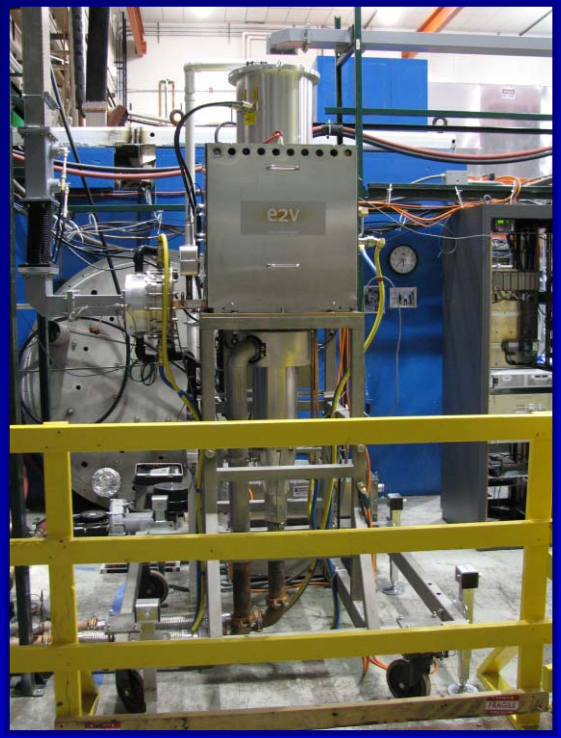
Finished Test Cryomodule

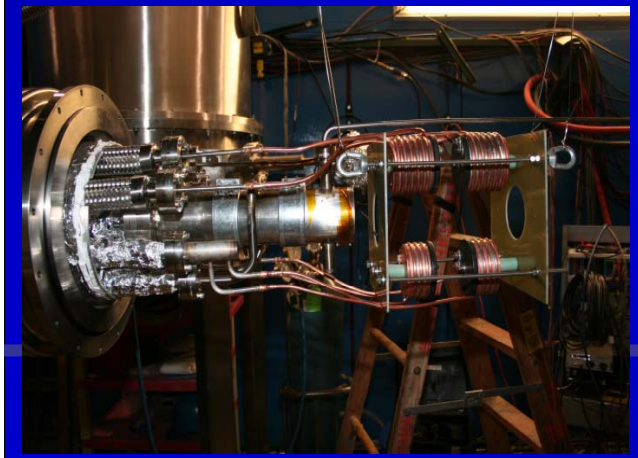


Insight from the Assembly

- First assembly revealed no significant design problems
- Fast, easy assembly (once we had all parts…)
- Fixed alignment concept works well
- Full 3D modeling (including assembly drawings) extremely helpful
- Tight tolerances are cost drivers ⇒ spec carefully!
- Several small improvements have been applied to the full injector module design to reduce cost further

Test Infrastructure



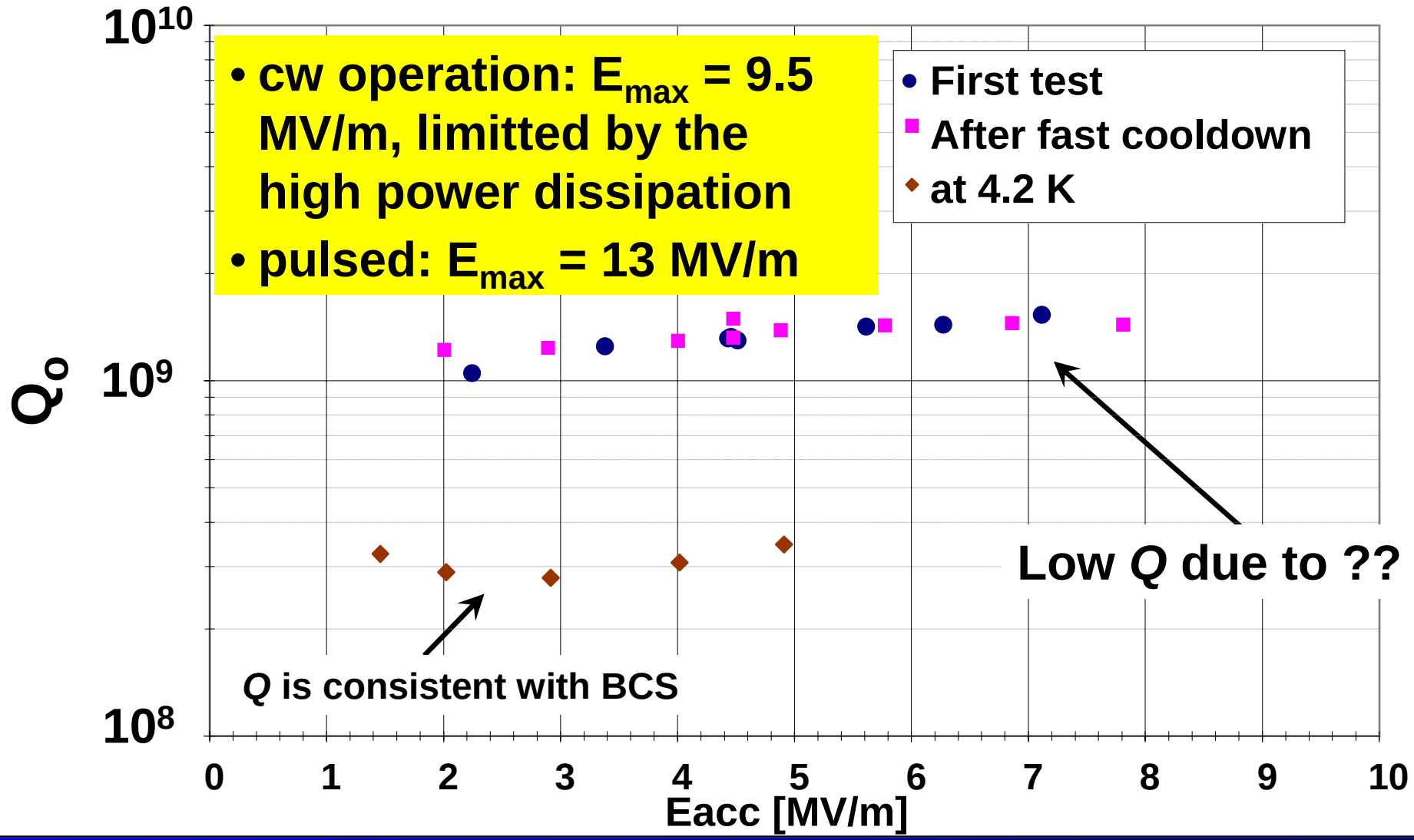


- 135 kW cw power klystron (e2v)
- Cold-box with 2K, 5K, 80K heat exchanger
- 50 W @ 1.8K pumping skid/ refrigerator

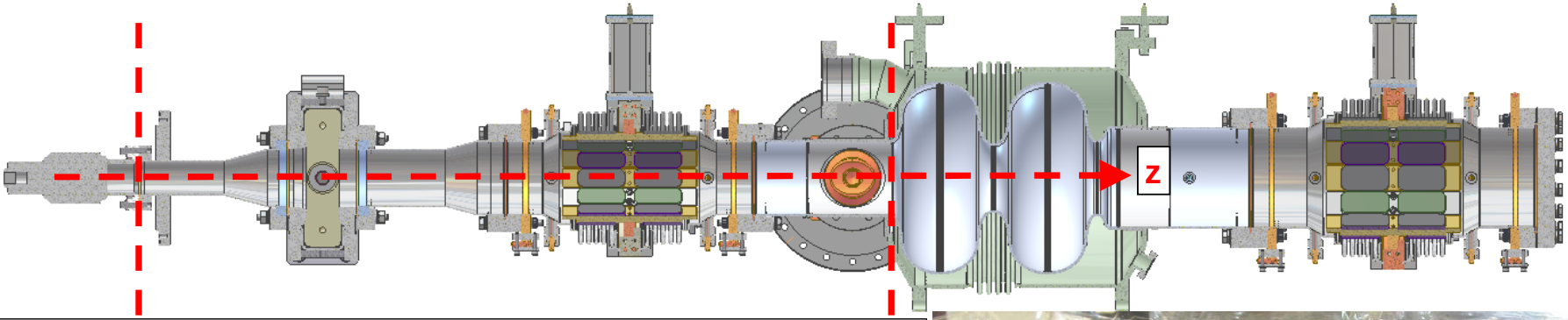
HTC Test Result

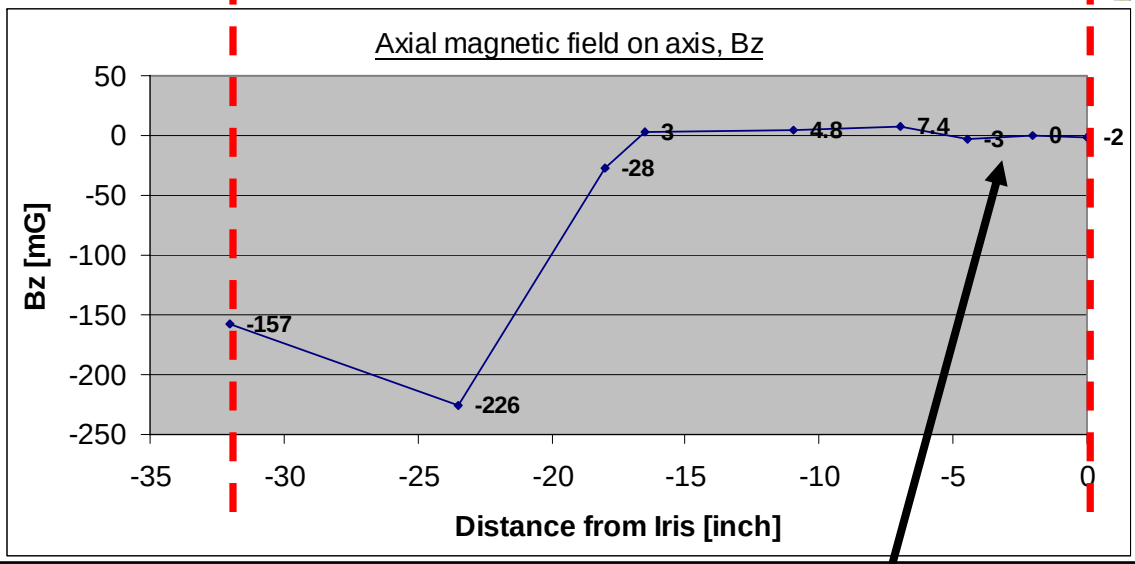
- The cryogenic system performed well
  - quick cryostat cool down and warm up (24 to 48 hours)
  - stable operation at low temperatures (1.6 K to 2 K)
- The cold mass shifted during cool-down as predicted (agreement better than ±0.1 mm)
- Q vs. E measurements showed a low intrinsic quality factor ($Q=1.5 \cdot 10^9$ at 1.8 K)
- Initial studies on microphones feedback show promising results
- HOM measurements showed no high Q modes

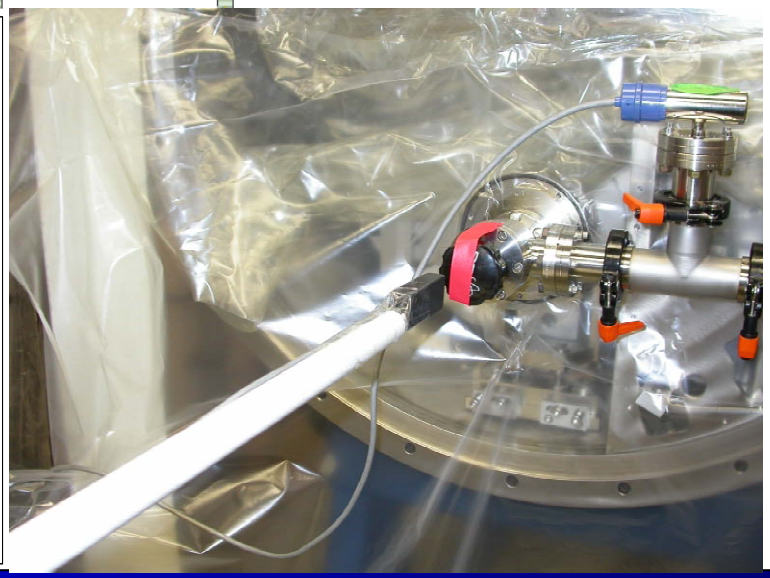
HTC Test Result: Q(E)



Residual Magnetic Field? Very low…



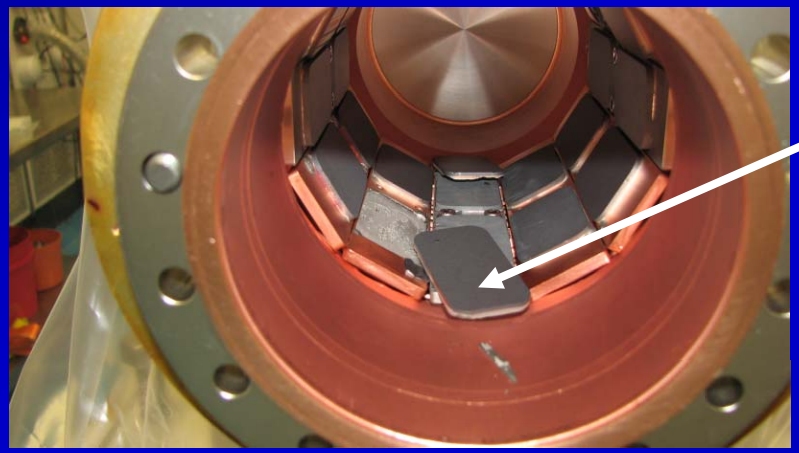




B < 5 mG

Source of Low Q_0?

- Fast cool-down excludes Q-disease
- Checked residual magnetic field: very low
- Disassembled cryostat, and found:



Two ferrite tiles cracked and dropped; found ferrite chips in the cavity beam pipe…

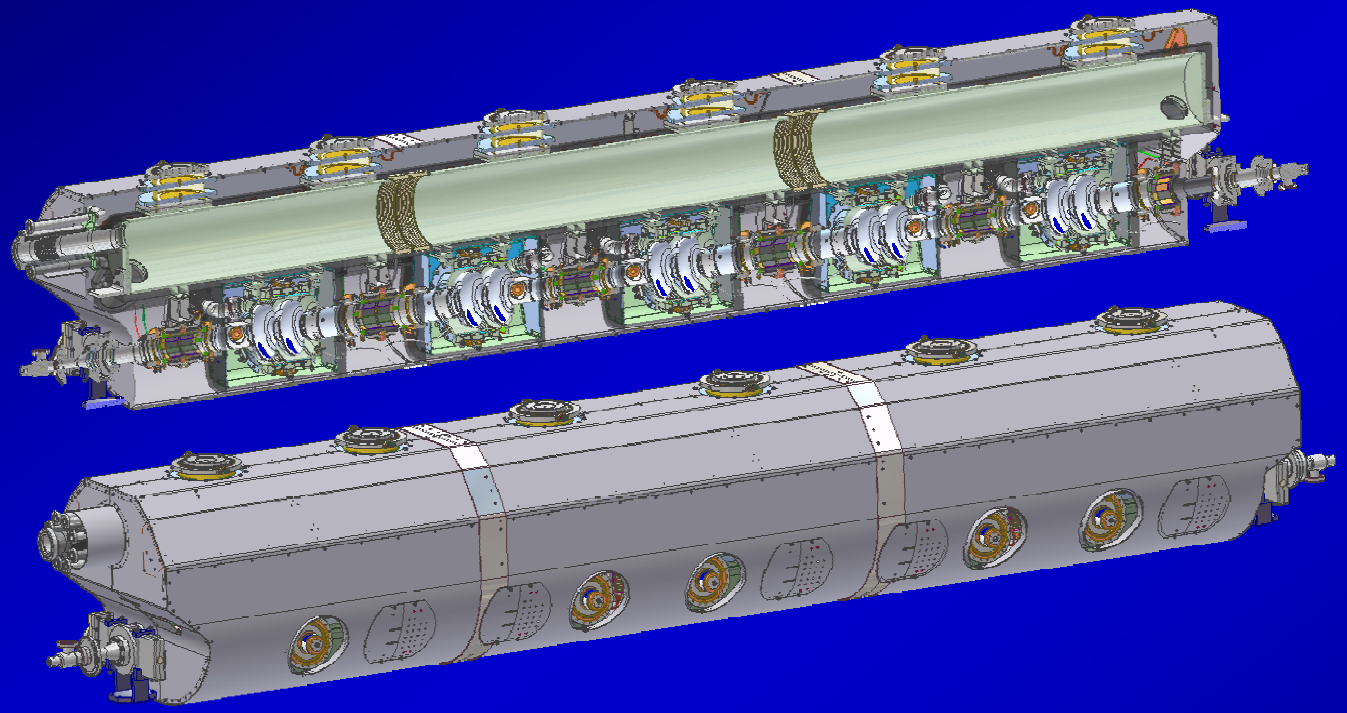
- But: retested HTC cavity vertically after removing ferrite, and Q is still low ($3 \cdot 10^9$)!?

Present Status and Future Plans

Cryovessel Fabrication

- All cryovessel parts have been ordered and are presently under fabrication at vendor side
- Delivery: 9/07 – 12/07

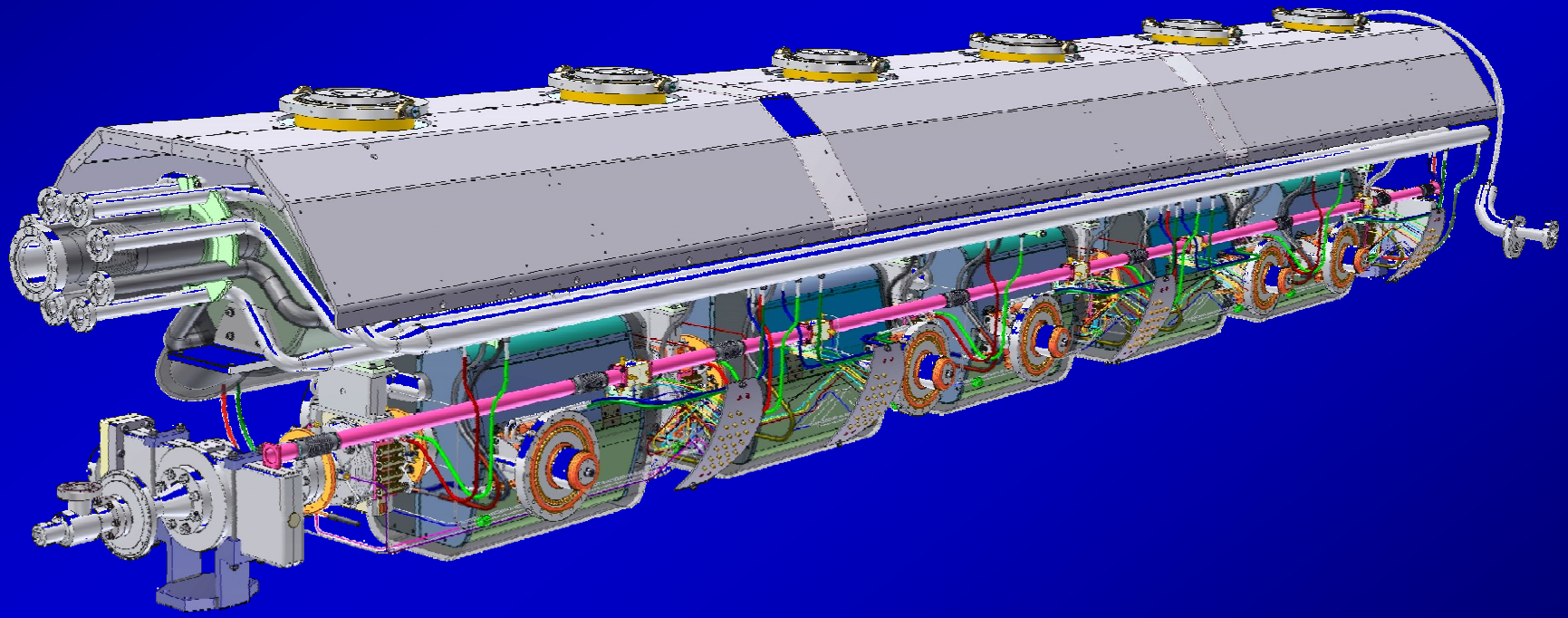
Cryovessel Assembly



- Assembly of cryovessel will start next month at Cornell
- Pending further results on low intrinsic cavity Q in HTC

ERL Injector Schedule

- Cryomodule assembly 11/07 – 3/08
- 100 mA beam test in 2008



This is going to be exciting!

Cornell ERL SRF Team

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