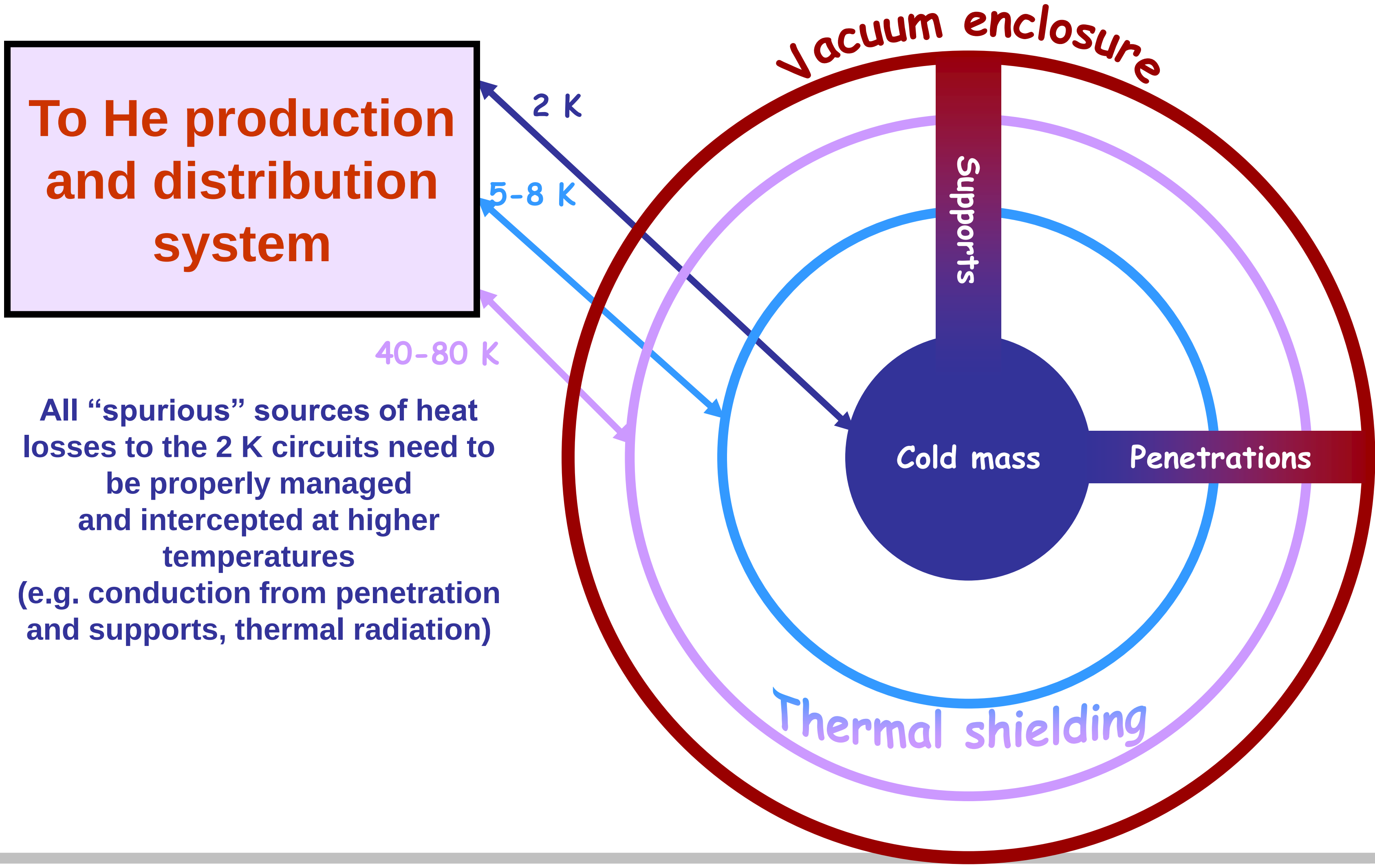
CRYOSTATS

Jean Delayen

Center for Accelerator Science
Old Dominion University
and
Thomas Jefferson National Accelerator Facility

“Cartoon” view of the system



All “spurious” sources of heat losses to the 2 K circuits need to be properly managed and intercepted at higher temperatures
(e.g. conduction from penetration and supports, thermal radiation)

Basic Functions of a Cryomodule

- In SRF application the cryomodule provides:
  - Cryogenic environment for the cold mass operation
    - Cavities/Magnets in their vessels filled with sub atmospheric He at 2 K
    - He coolant distribution at required temperatures
    - Low losses penetrations for RF, cryogenics and instrumentation
  - Shield for the sources of “parasitical” heat transfer from room to cryogenics temperature produced by three mechanisms
    - thermal radiation
    - conduction
    - convection
    - (To mitigate loads at 2 K all heat fluxes need to be intercepted at higher T)
  - Structural support of the cold mass
    - Issues concerning different thermal contractions of materials
    - Provide precise alignment capabilities and reproducibility with thermal cycling
- The cryomodule contains a variety of complex technological objects: cavities and their ancillaries, but also magnets and BPMs

Heat losses issues: Physical mechanisms

- Thermal radiation

$$\dot{Q} = S\varepsilon\sigma_{SB}\left(T_h^4 - T_c^4\right)$$

  - Radiated power from hot surfaces to vanishingly temperatures is proportional to T^4 (Stephan-Boltzmann). σ_{SB} = 5,67·10^{-8} [W m^{-2} K^{-4}]
    - Reduce the surface emissivity, ε (material and geometry issue)
    - Intercept thermal radiation at intermediate temperatures by means of thermal shields

- Heat conduction

$$\dot{Q} = \frac{S}{L}\int_{T_c}^{T_h} k_{th}(T)\,dT$$

  - A SRF module has many penetration from the room temperature environment (RF couplers, cables, …)
    - Proper choice of low thermal conduction, k_{th}, materials whenever possible
    - Minimize thermal paths from r.t. and provide thermalization at intermediate temperatures.

- Convection
  - Convective exchange from r.t. is managed by providing insulation vacuum between the room temperature vessel and the cold mass

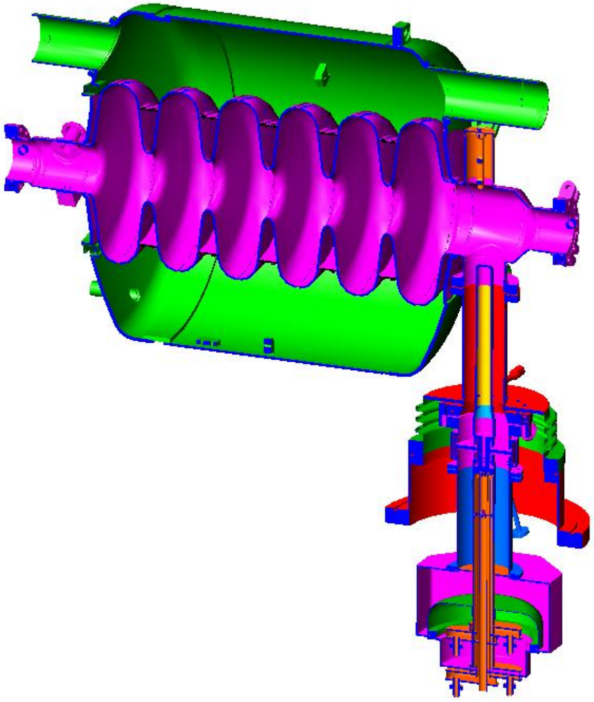
$$\dot{Q} = S\,h\left(T_h - T_c\right)$$

Magnetic Shielding

- Reduce 1 G background field to < 10 mG
  - Attenuation factor = 1 / 0.010 = 100
    - The 1 G background field includes earths field as well as fields from other sources (ie. rebar and magnet stray fields)
- Minimize shielding cost
  - Maximize shielding performance
  - As much commonality between Medium and High Beta shields as possible
- Shield around components of cryomodule (geometric constraints)

Instrumentation

Signal Description	Device	# Pins/ Device	Qty.	Feed-thru
RF	HOM	N/A	2	N-type
RF	Field Probe	N/A	1	N-type
Low I, V	Diode	2	4 (x2)	Part of 24-pin UHV Ceramic
Low I, V	Liquid Level	4	1*	Part of 24-pin UHV Ceramic
High I, V	Tuner Motor	2	1	Part of 24-pin UHV Ceramic
High I, V	Limit Switches	4	2	Part of 24-pin UHV Ceramic
High I, V	Heater	4	1	Part of 24-pin UHV Ceramic
Vacuum	Cold Cathode Gauge	N/A	1 (x2)	SHV
Vacuum	Thermocouple Gauge	N/A	1	Standard TC Gauge Connector



Instrumentation (SNS CM)

- Liquid Helium Level Sensor
  - CEBAF Drawing # 11161-C-0069 (American Magnetics, Inc.)
  - Quantity : 2 per CM, located in Helium Vessels nearest each End Can
  - Supported from Cavity Reinforcing Ring
  - Modifications for Radiation Resistance:
    - Kapton Leads
    - Replace Teflon Plug
  - Other Modifications:
    - Additional Sheath required to stabilize readings

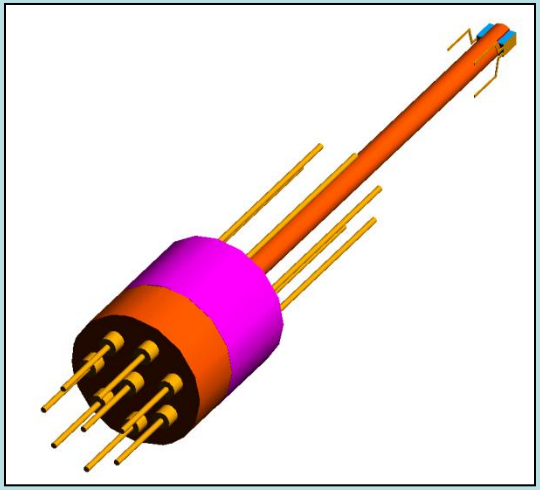
- Pressure Transducer
  - Baratron, Range: 0-100 Torr
  - Quantity : 1 per CM
  - Located on Return End Can to measure return pressure PRIOR to HX
  - Accessible in Tunnel therefore redundant sensors not required.

Instrumentation (SNS CM)

- Heaters
  - Minco P/N HK15097, 100 W, 28 Vdc, 7.8 Ω (Used in Original CEBAF)
  - Quantity : 1 per Helium Vessel
  - Mounting:
    - Heater is attached to G11 card with acrylic adhesive
    - Card is bolted to block inside HV shell
  - Modifications for Radiation Resistance:
    - Kapton Leads
    - G11 Substrate
    - Acrylic Adhesive

Instrumentation (SNS CM)

- Thermometry
  - Measurements:
    - Cavity cell and beam pipe temperatures
    - Primary and shield process temperatures
    - Heat Exchanger Terminal Temperatures
    - FPC Outer Conductor and Water Temps
  - Outside CM: Thermocouples (FPC Warm End)
    - Less expensive than RTDs or Diodes
    - Simplifies control system
  - Inside CM: Cernox CX-1050-SD OR DT-470-SD
    - Both are 4-wire hermetic chip packages
    - Quantities per CM :
      - Medium β – 20(x2 per location)
      - High β – 24(x2 per location)
    - Mounting: Chip is epoxied in place, leads are heat sunk



In-process Thermometers are attached to a G11 stick mounted on 8-Pin Feed-thru

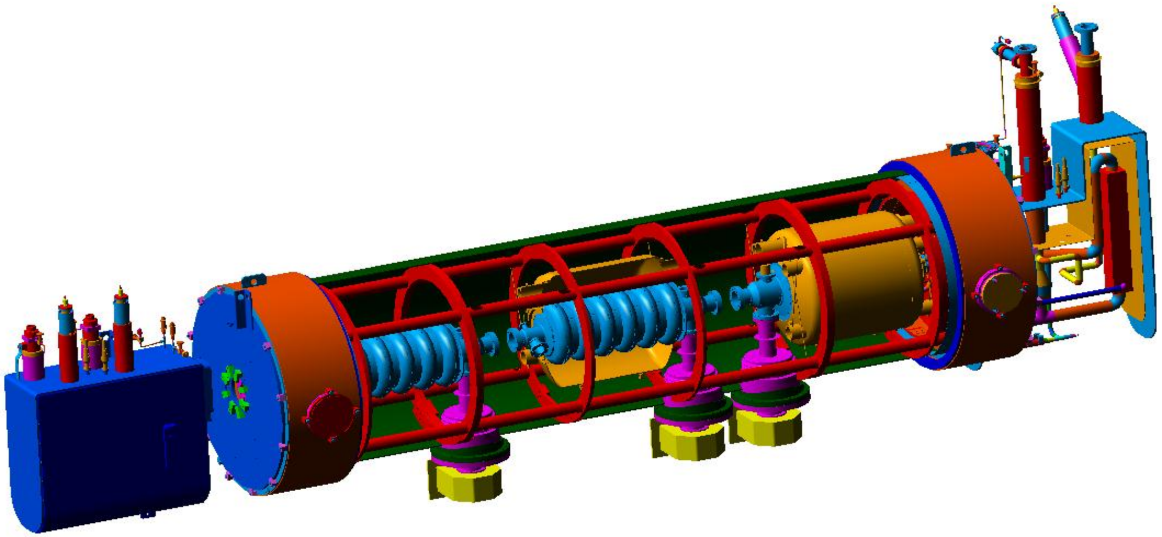
Cernox vs. Silicon Diodes

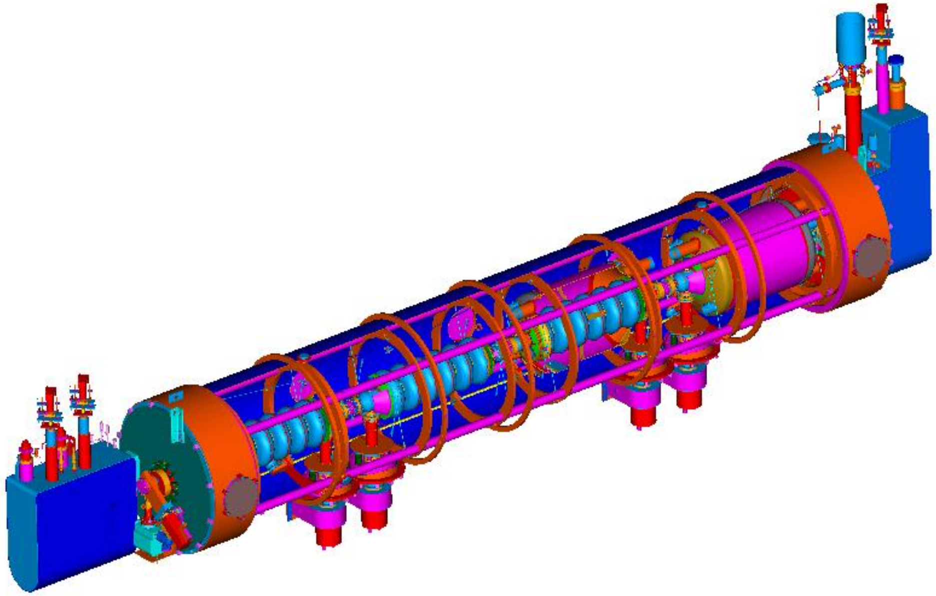
- Technical:
  - Cernox has higher radiation resistance
  - Silicon Diodes can be recalibrated in-situ using a pressure measurement with Baratron Gauge
  - Control system more complex for Cernox approach
- Cost: Cernox is more expensive (~250K)
  - Calibrated Cernox RTDs are 2 times more expensive than grouped Diodes ($537 vs $385) - ~$150 K
  - More complex controls for Cernox costs ~$100K (per H. Strong Estimate)

FPC Instrumentation

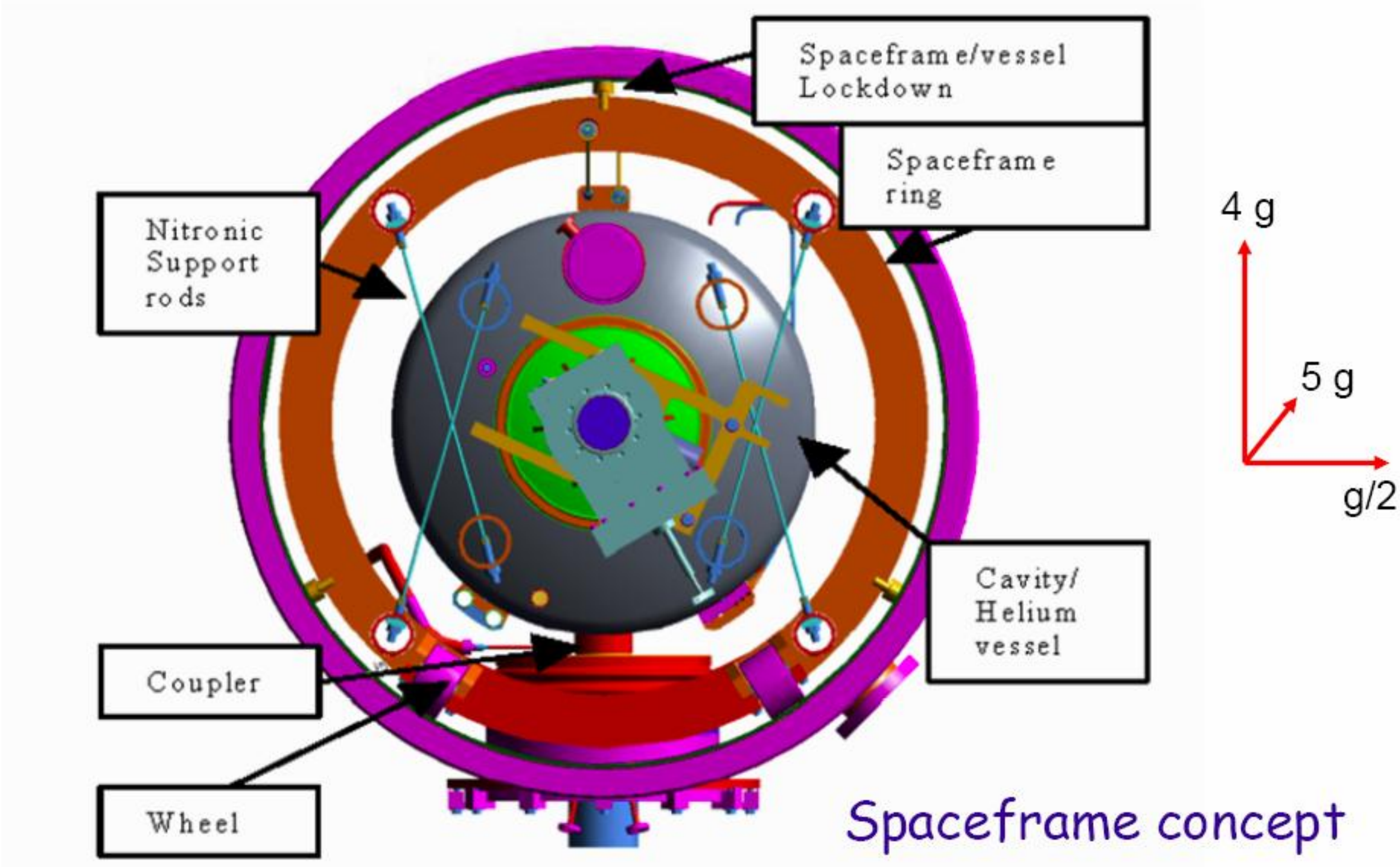
- Infrared Sensor
  - 1 per FPC
  - Monitors window temperature
- Arc Detector
  - 1 per FPC
  - Custom Photo-multiplier Tube Design
- Cold Cathode Gauge
  - 1 per FPC; sense pressure spikes during operation
  - Balzers, coaxial design, P/N IKR 060
- RTD/Diode on Outer Conductor (See Cavity Instrument Listing)
- Thermocouples near Warm End
  - 3 per FPC ; Water inlet & outlet, Helium Exhaust Temperature; K-Type
- Window Heater
  - 1 per FPC; mounted on Window-to-Outer-Conductor Flange
  - 100 W, 28 Vdc, 7.8 Ω
- Voltage Bias

SNS Medium and High Beta Cryomodules

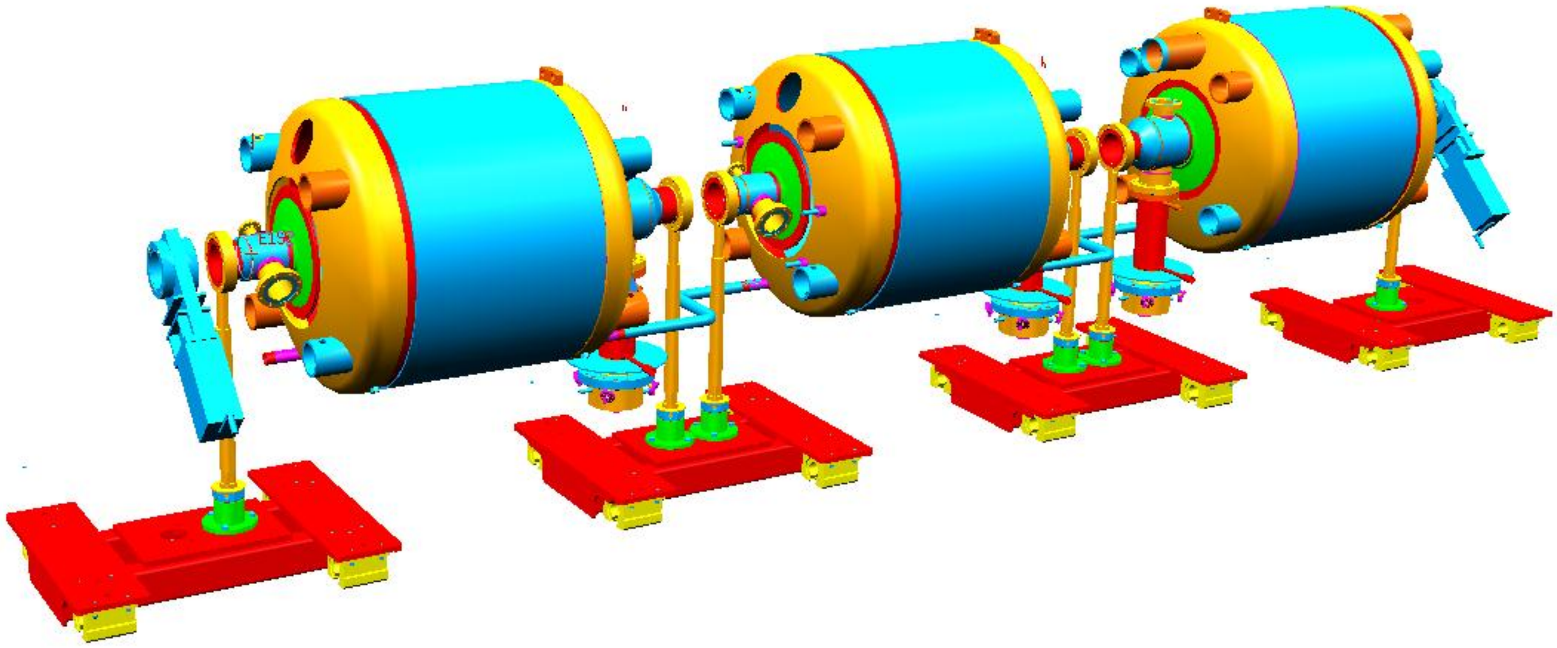




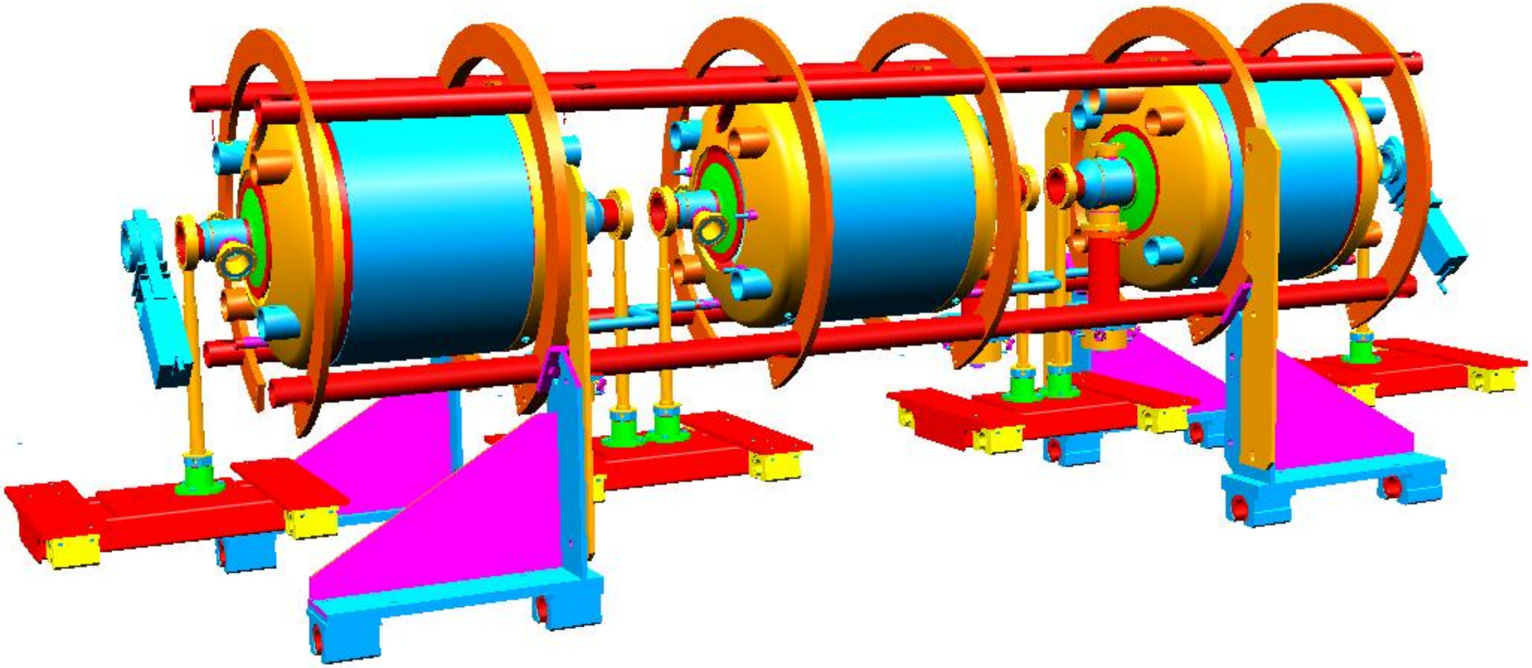
Cross Section



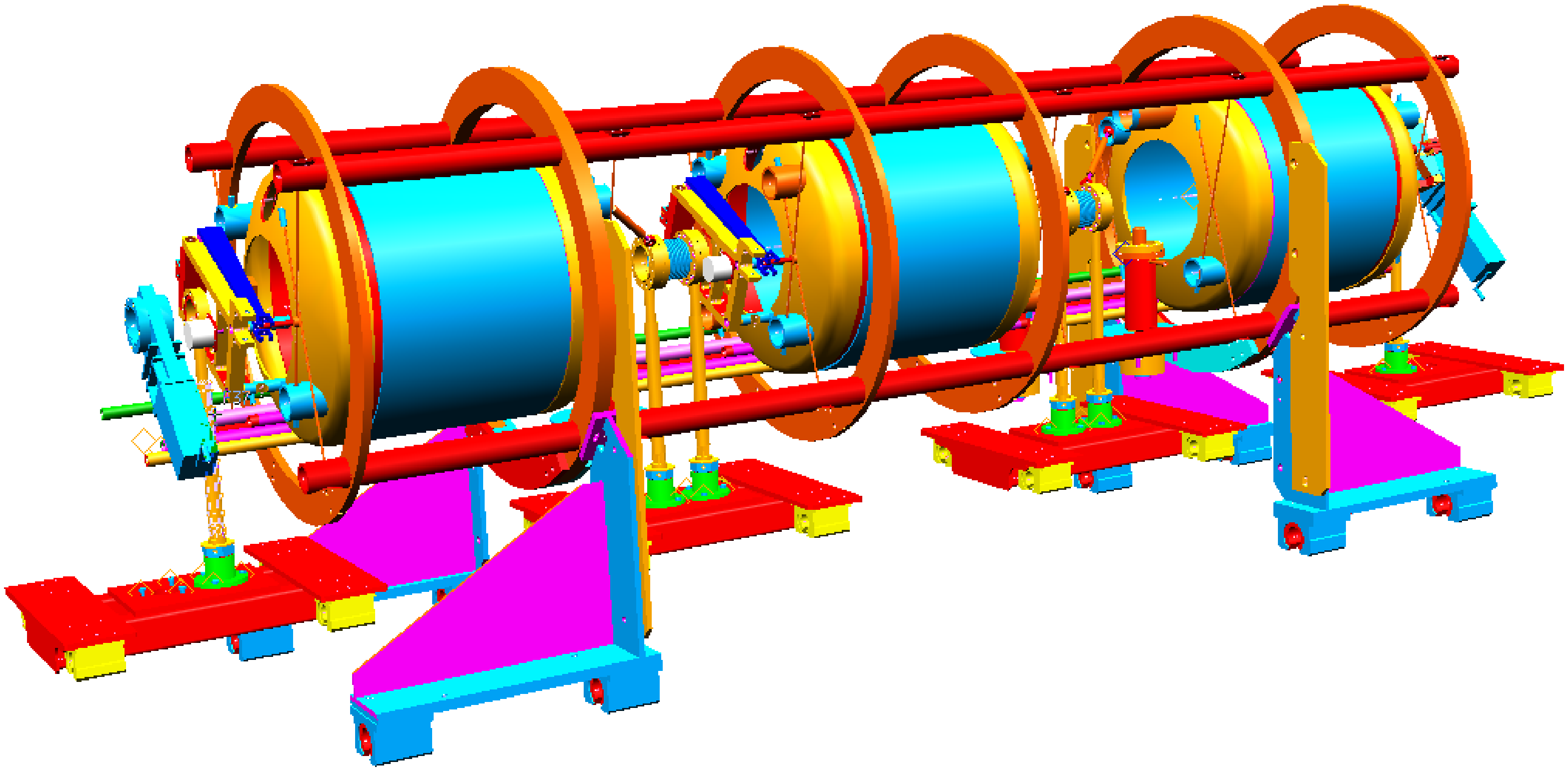
Cavity String Assembly on Cavity Assembly Bench in Clean Room



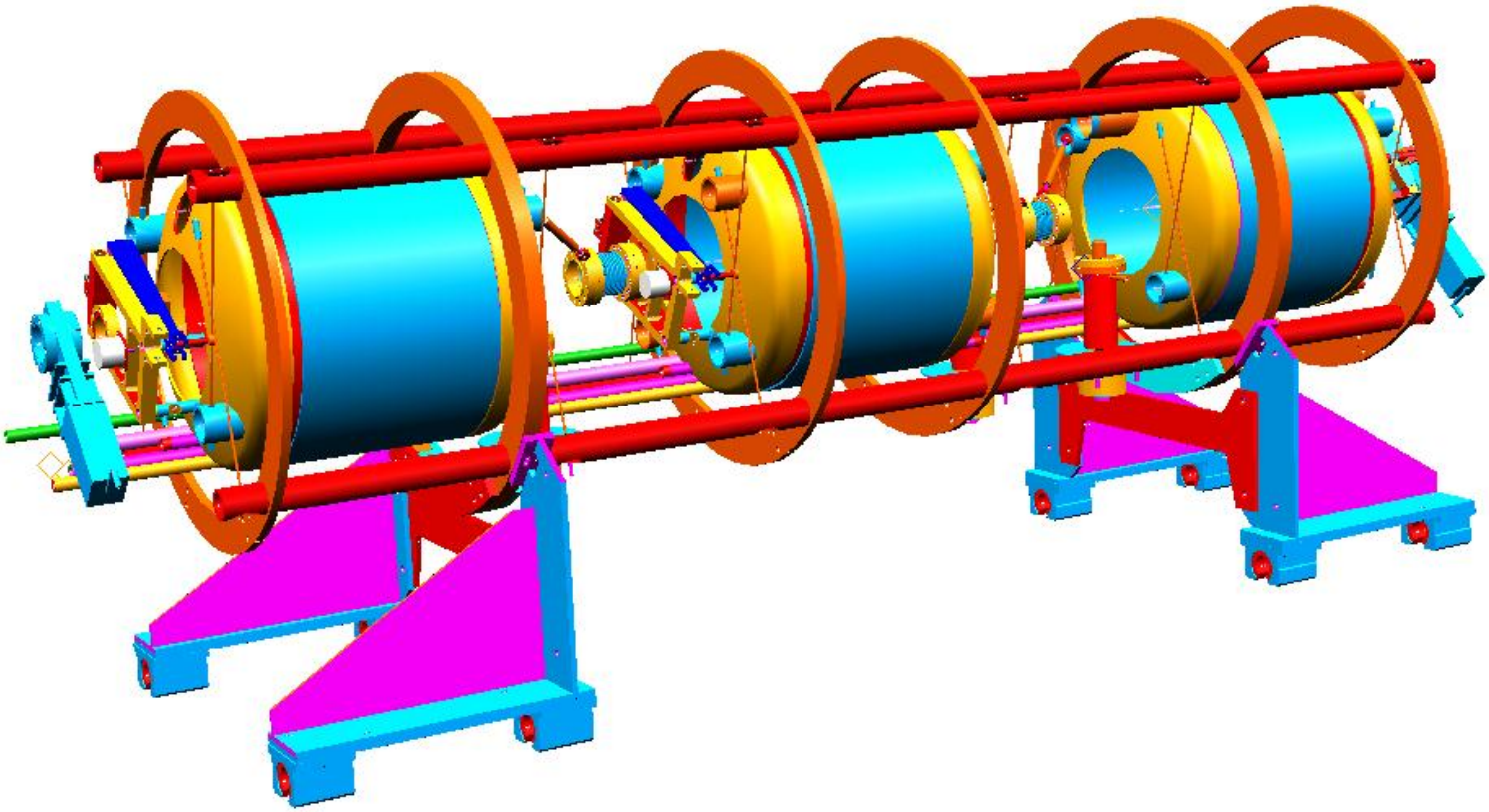
Installation of Frame Over Cavity String on CM Assembly Bench



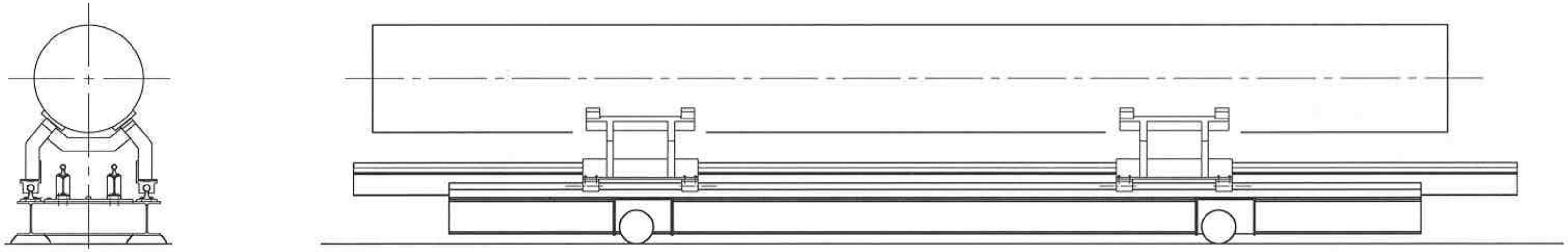
Cavity String Support Transfer from Lolly Pops to Nitronic Rods



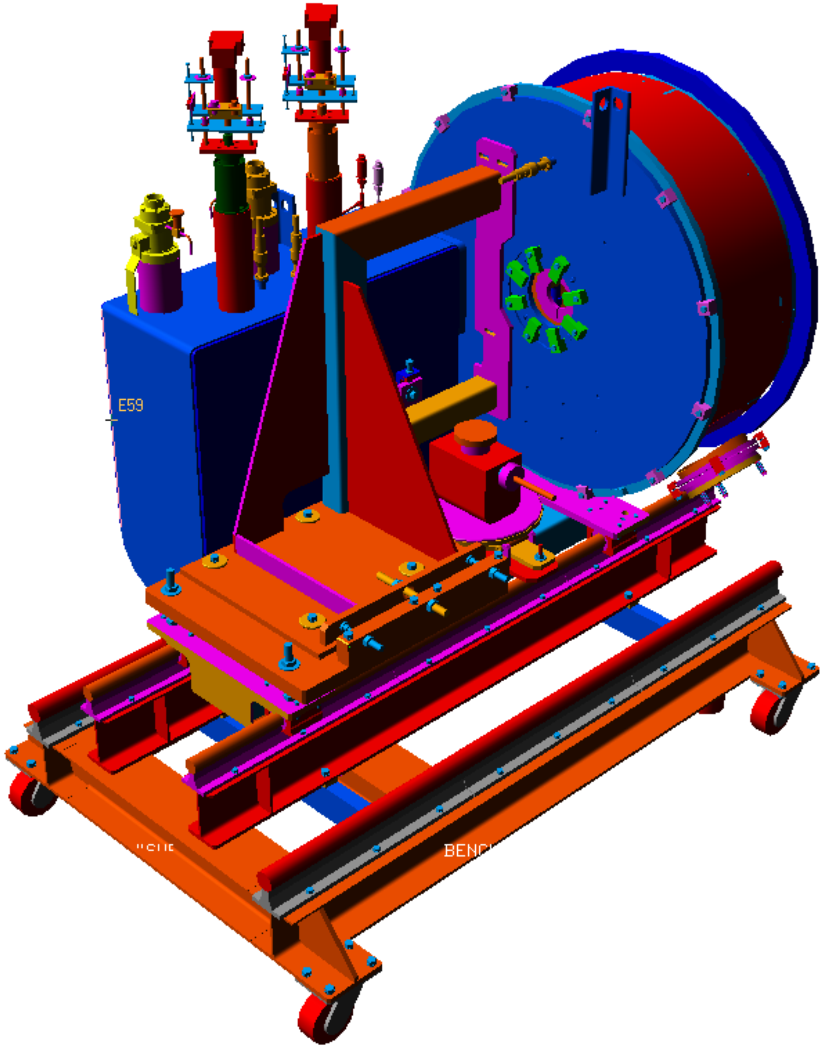
String Supported on Space Frame,To Be Inserted In Vacuum Tank



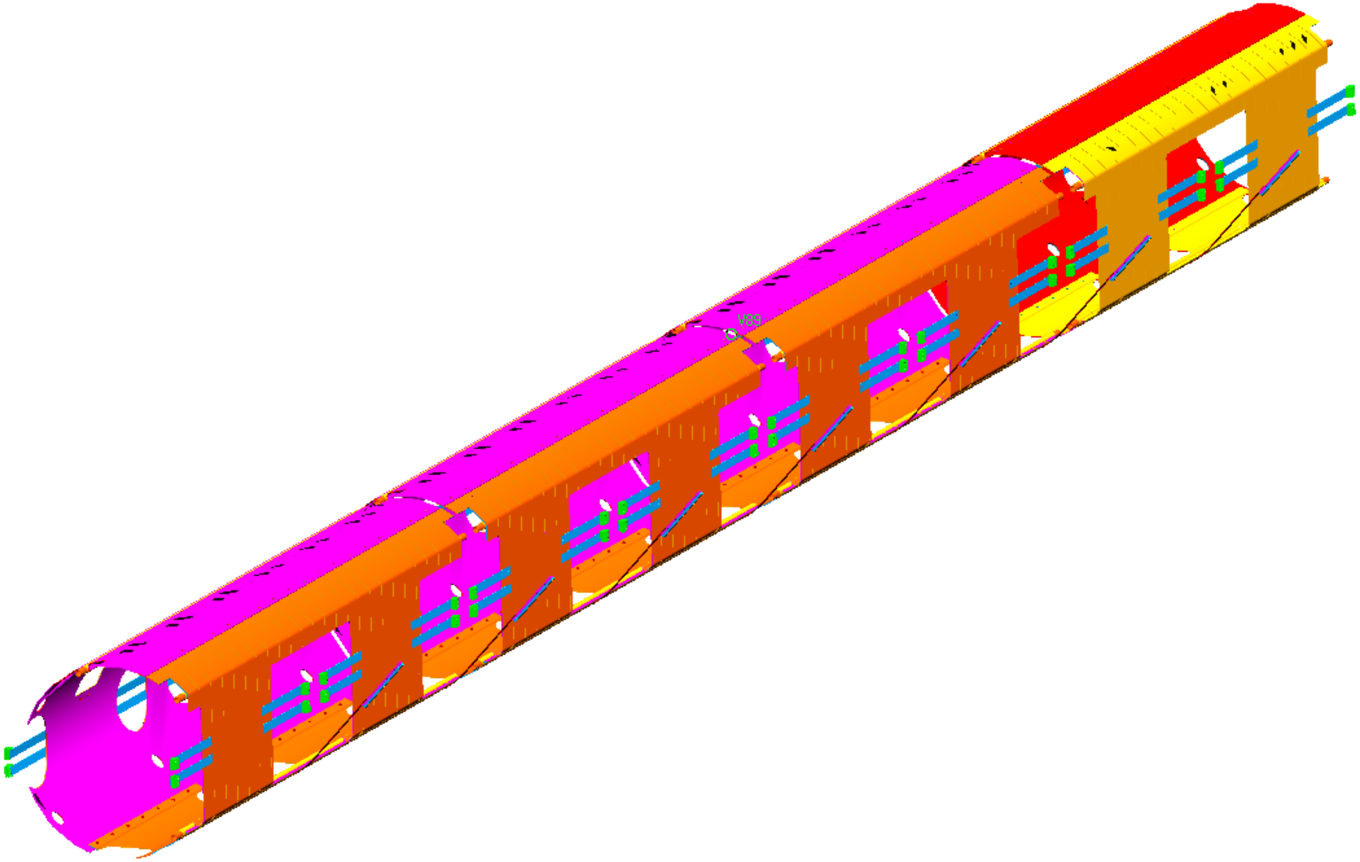
Transfer Bench with Vacuum Tank Ready to Accept Space Frame



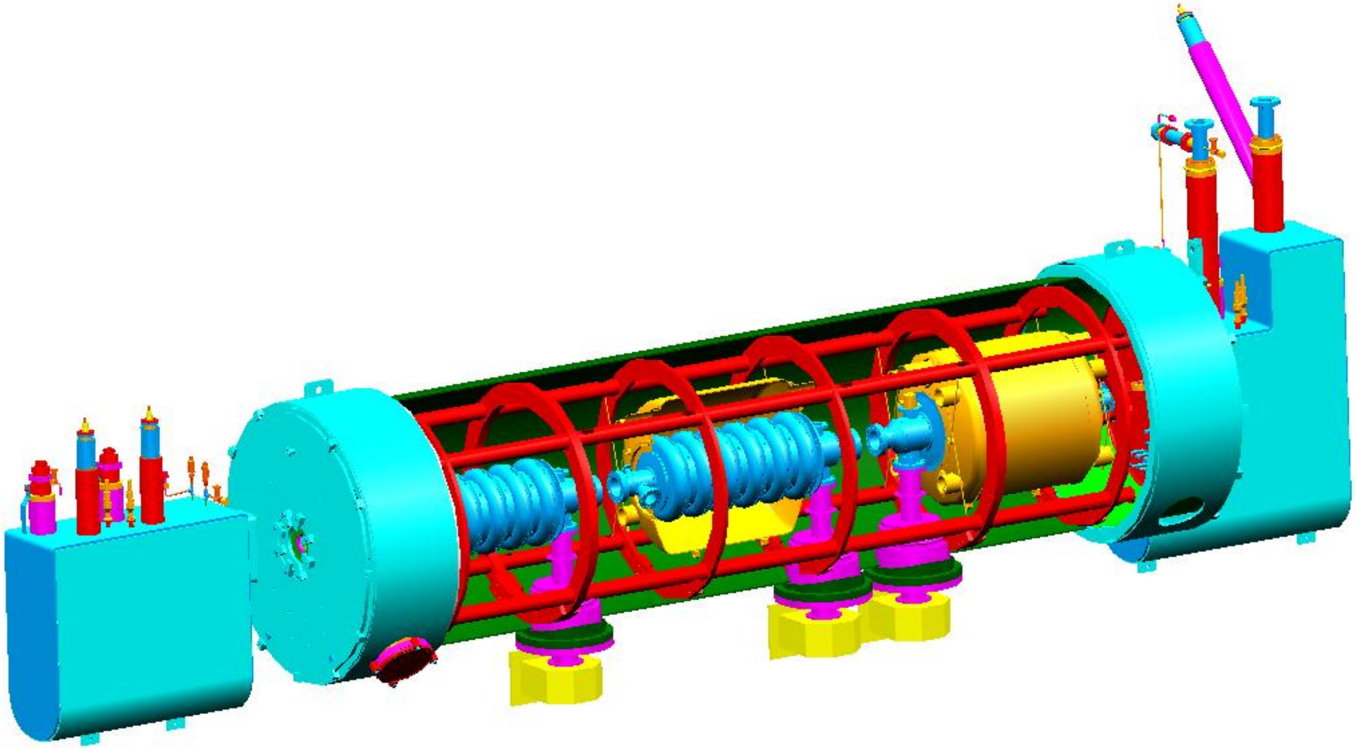
Installation of End Can on to Assembly Bench



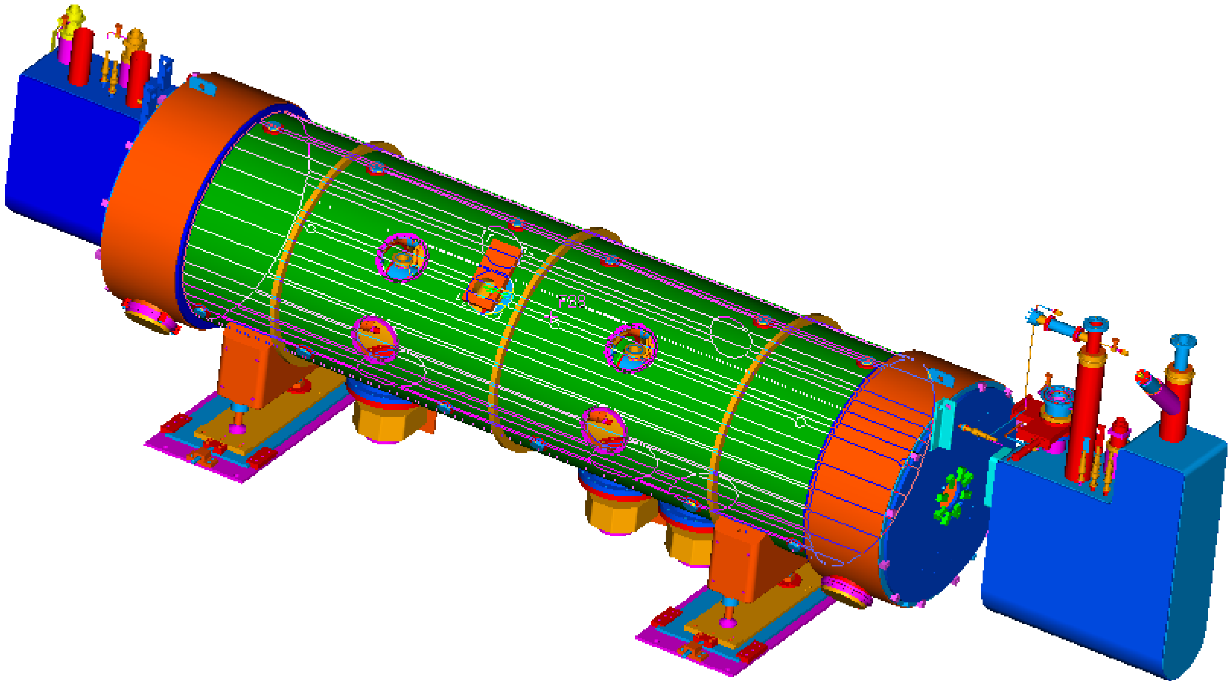
Shield Assembly (Upgrade)



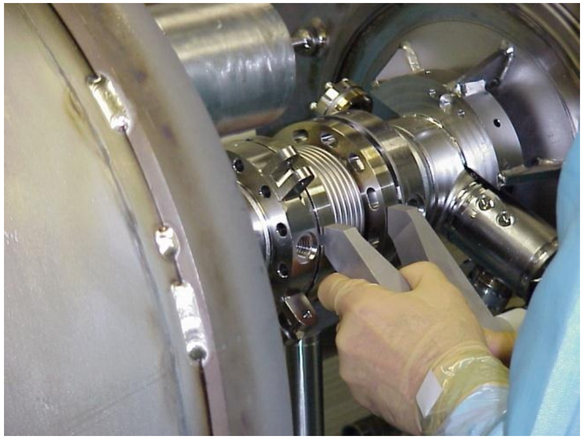
Production Cryomodule Cut-a-way

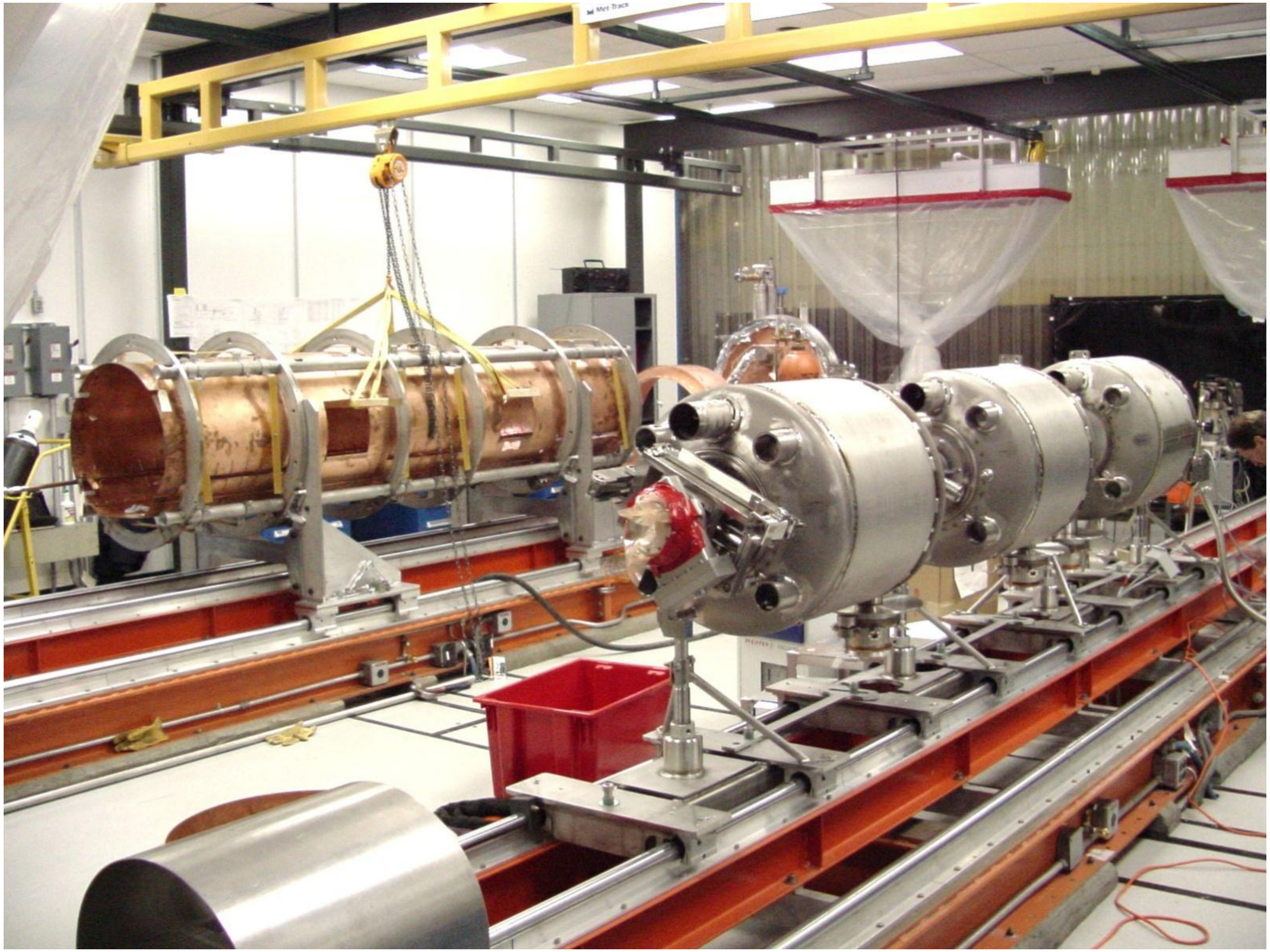


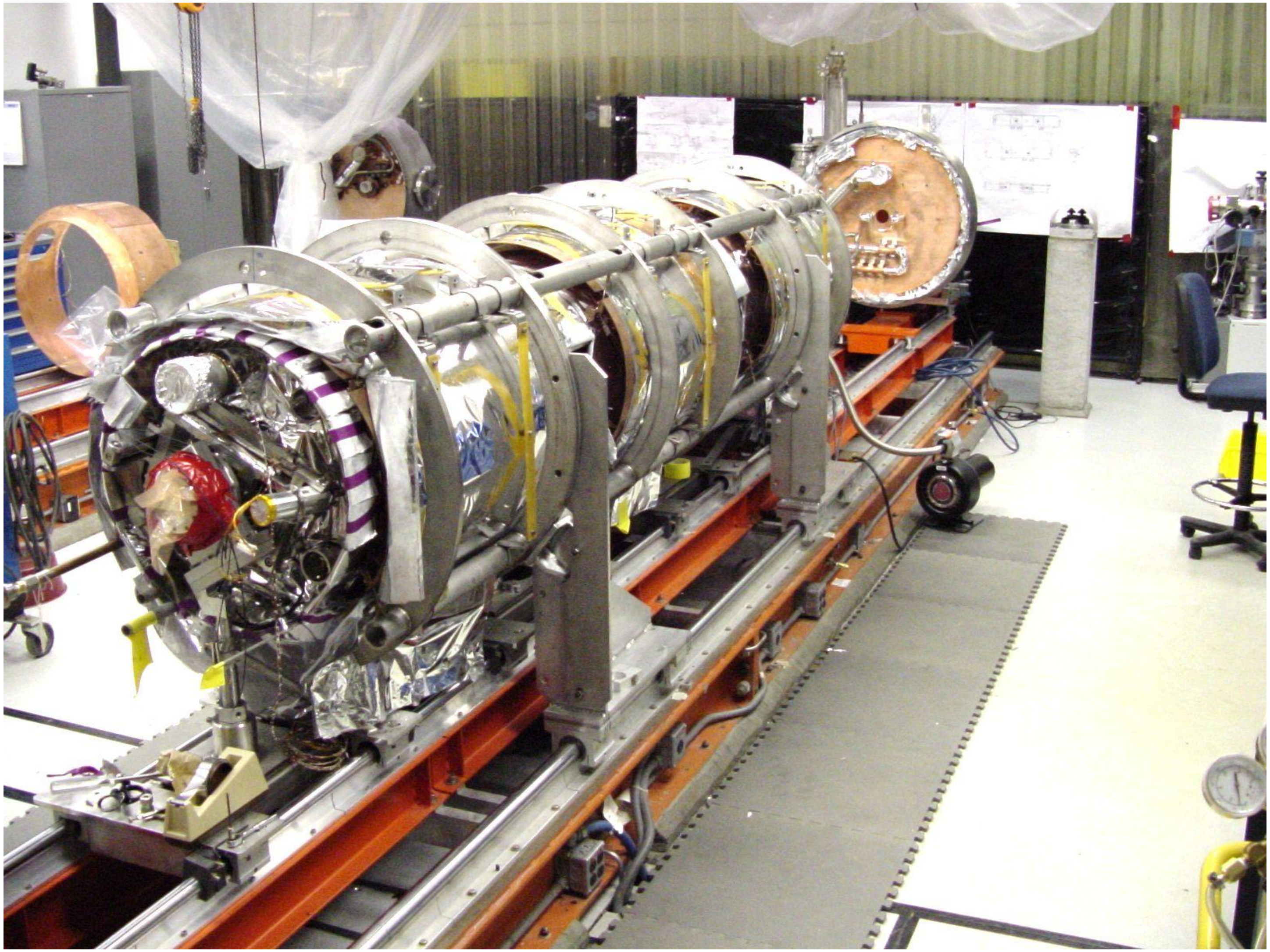
Completed Cryomodule on Support Stands

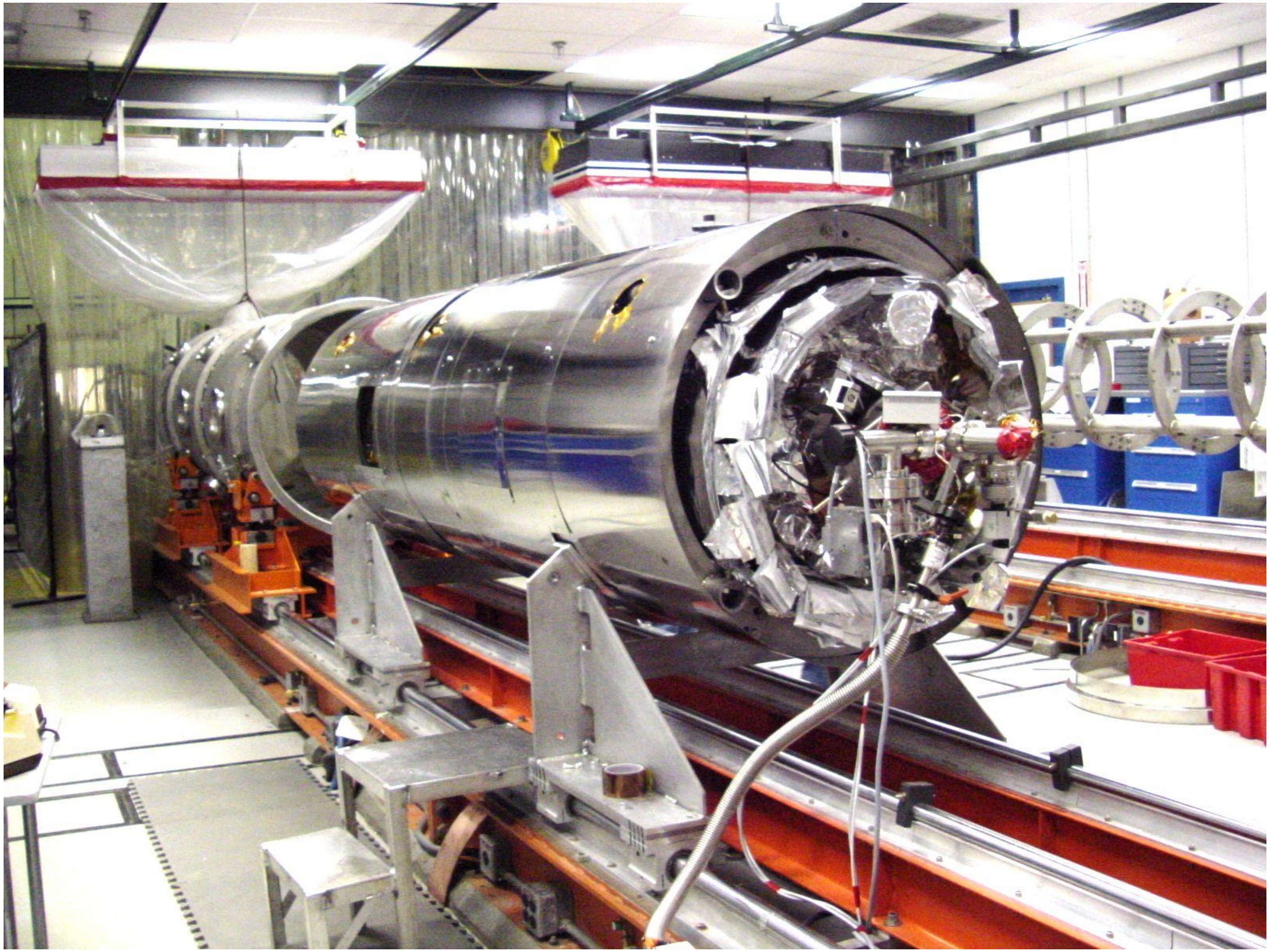


Cavity String Assembly

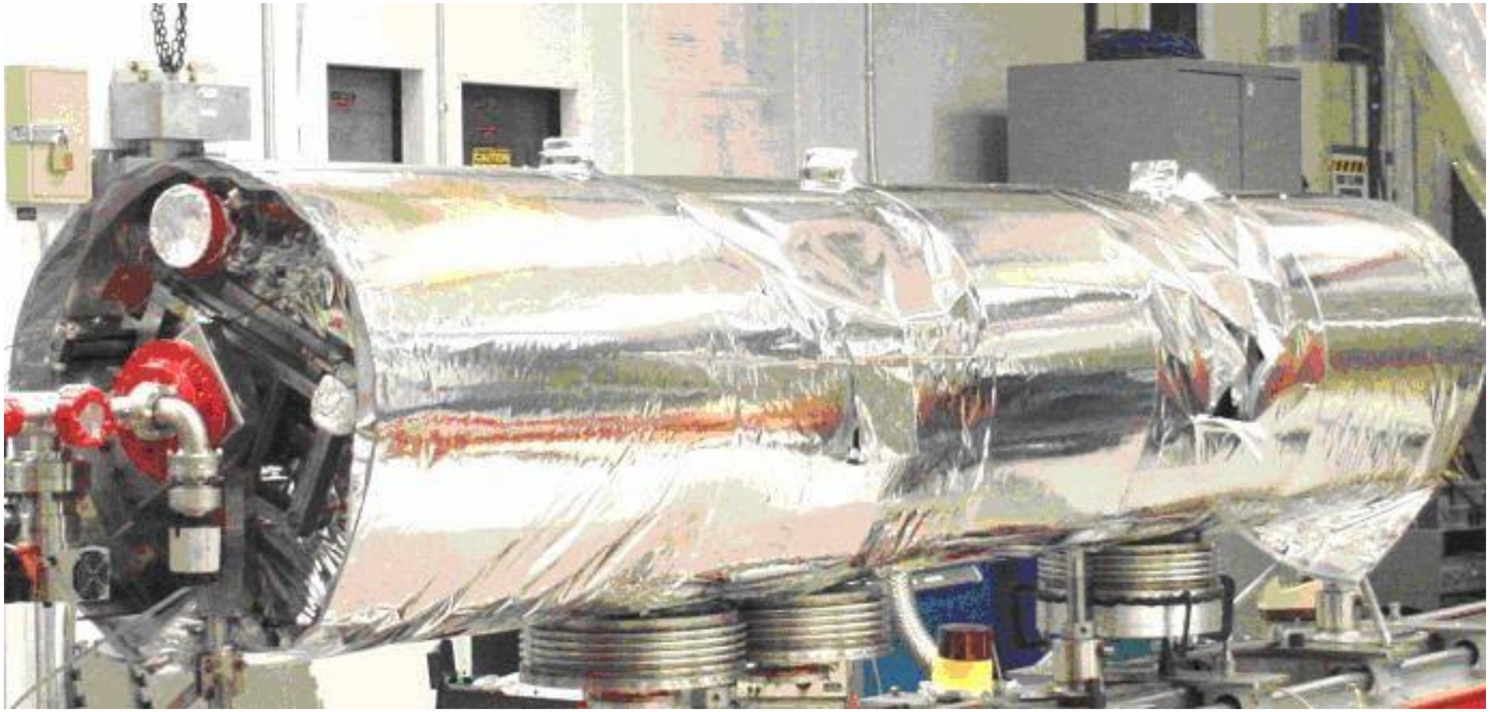


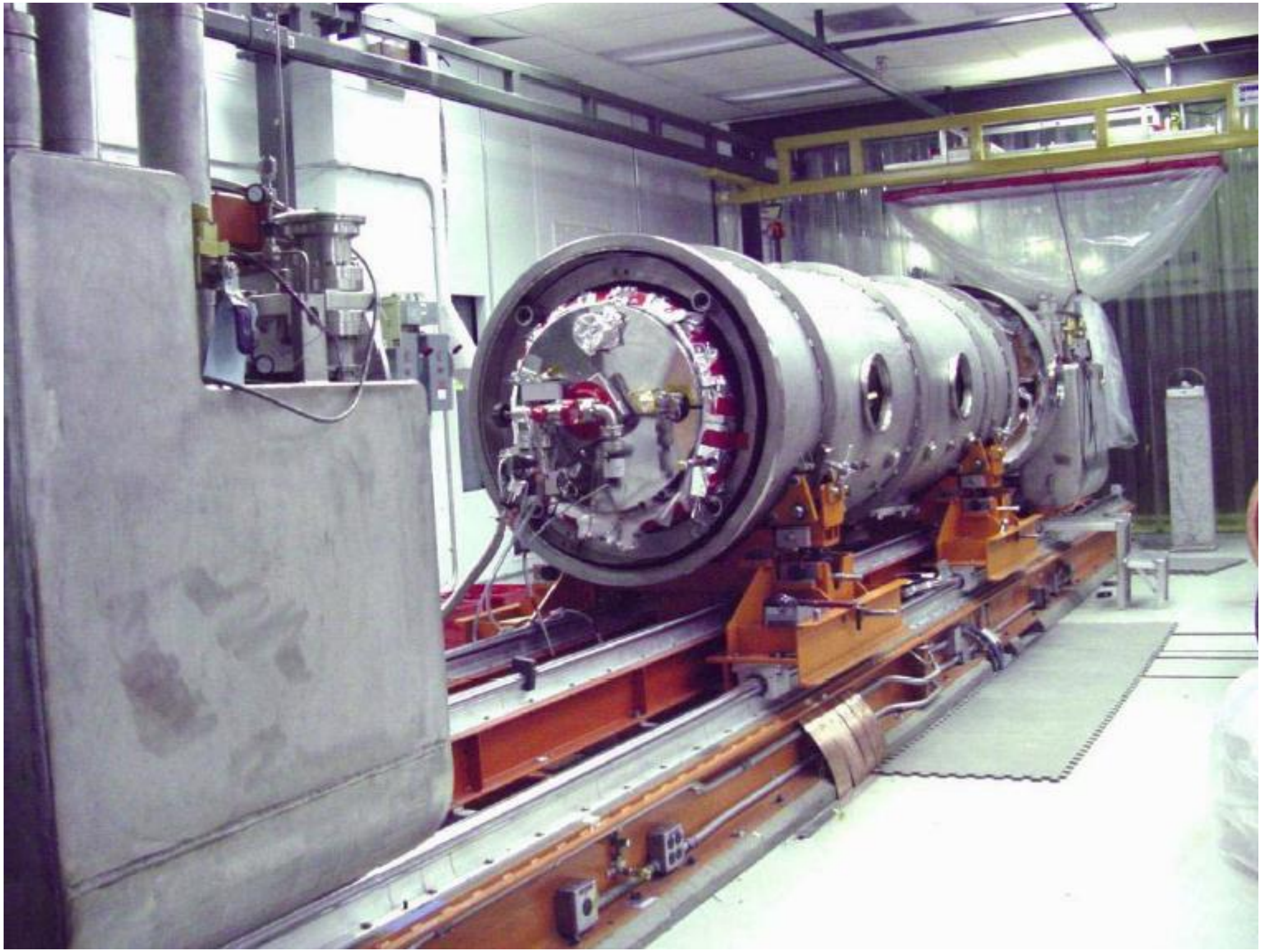




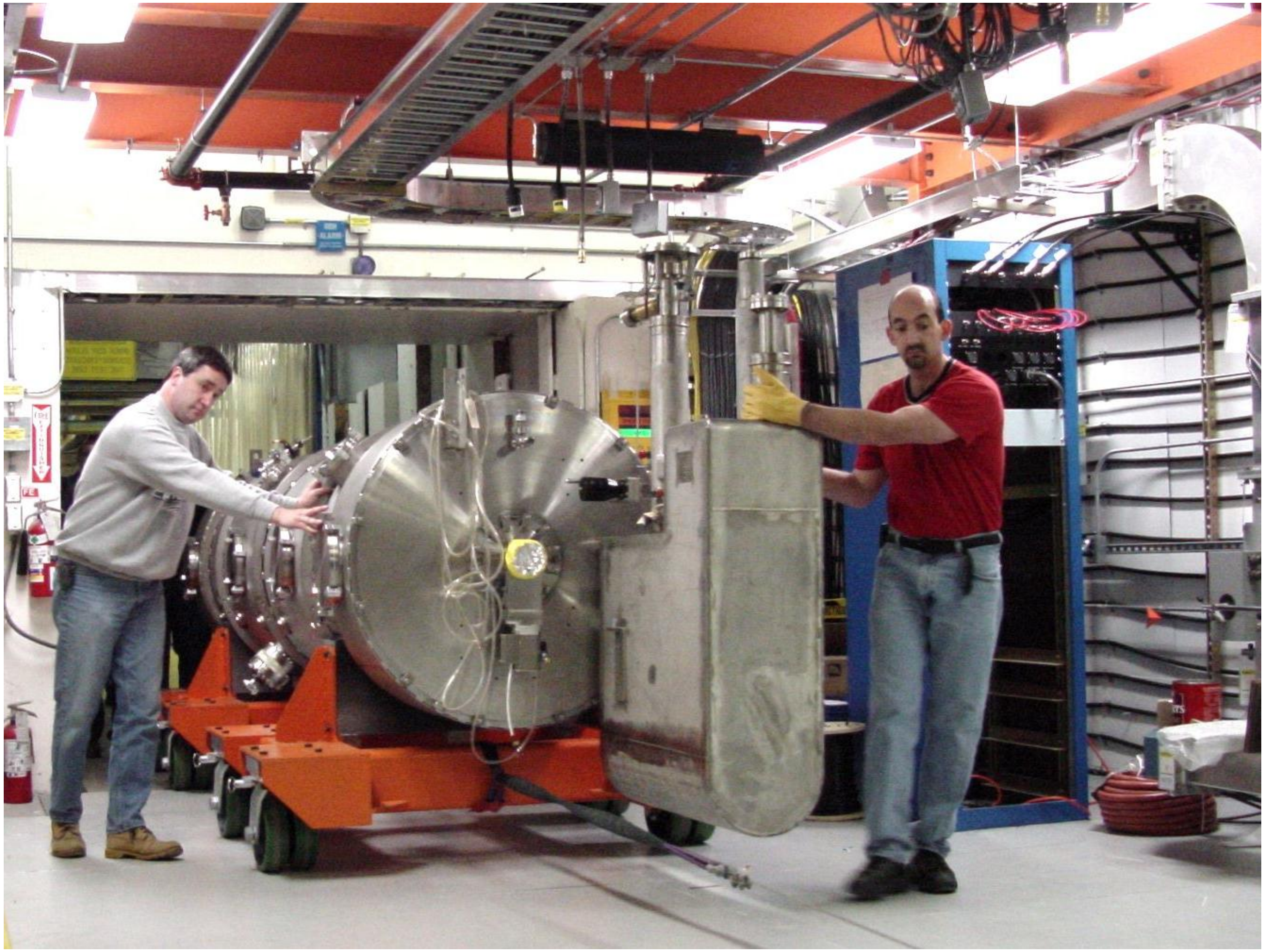


Superinsulation



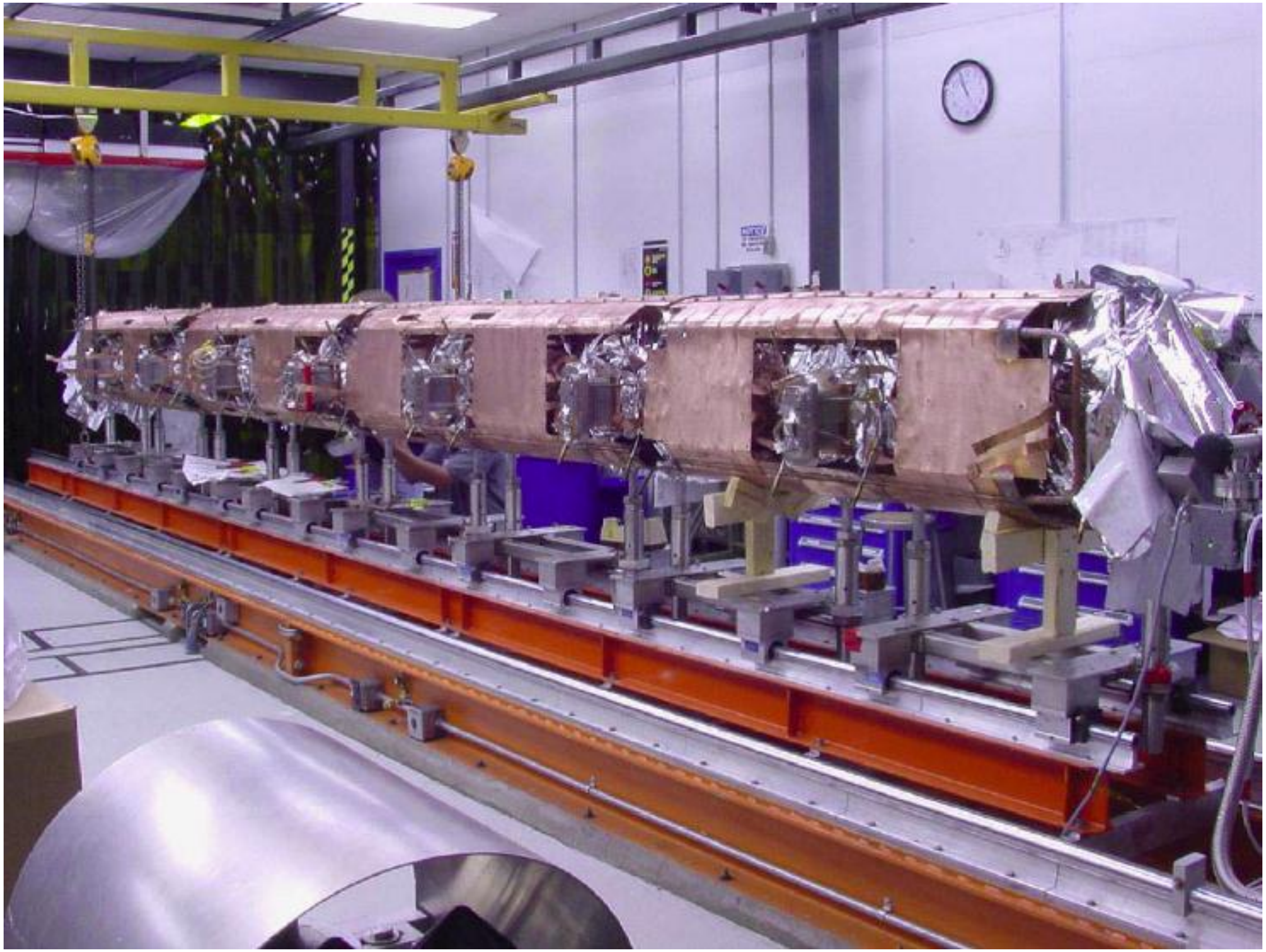


Cm in Test Cave



CEBAF Upgrade

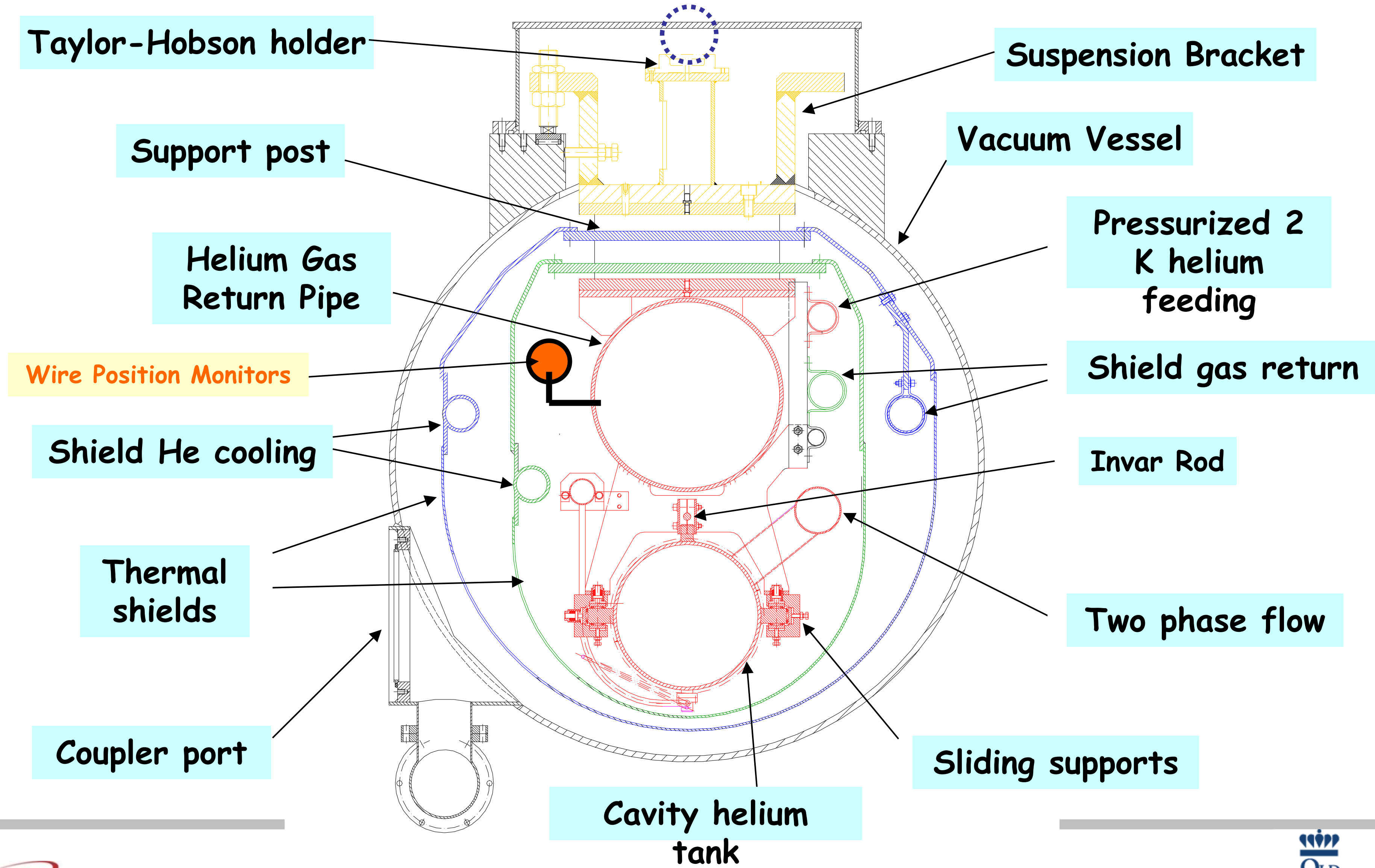
CEBAF Upgrade



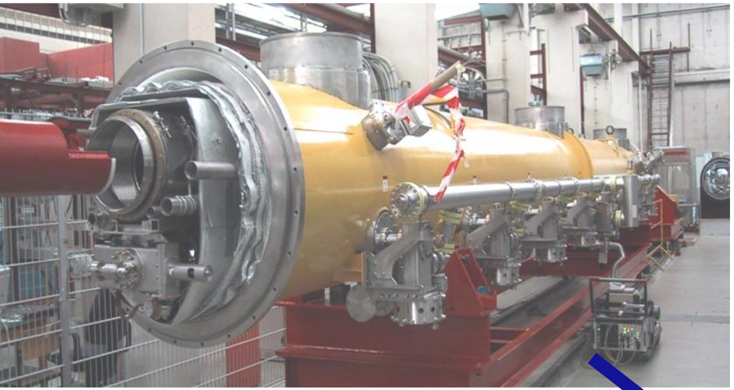
CEBAF Upgrade

CEBAF Upgrade

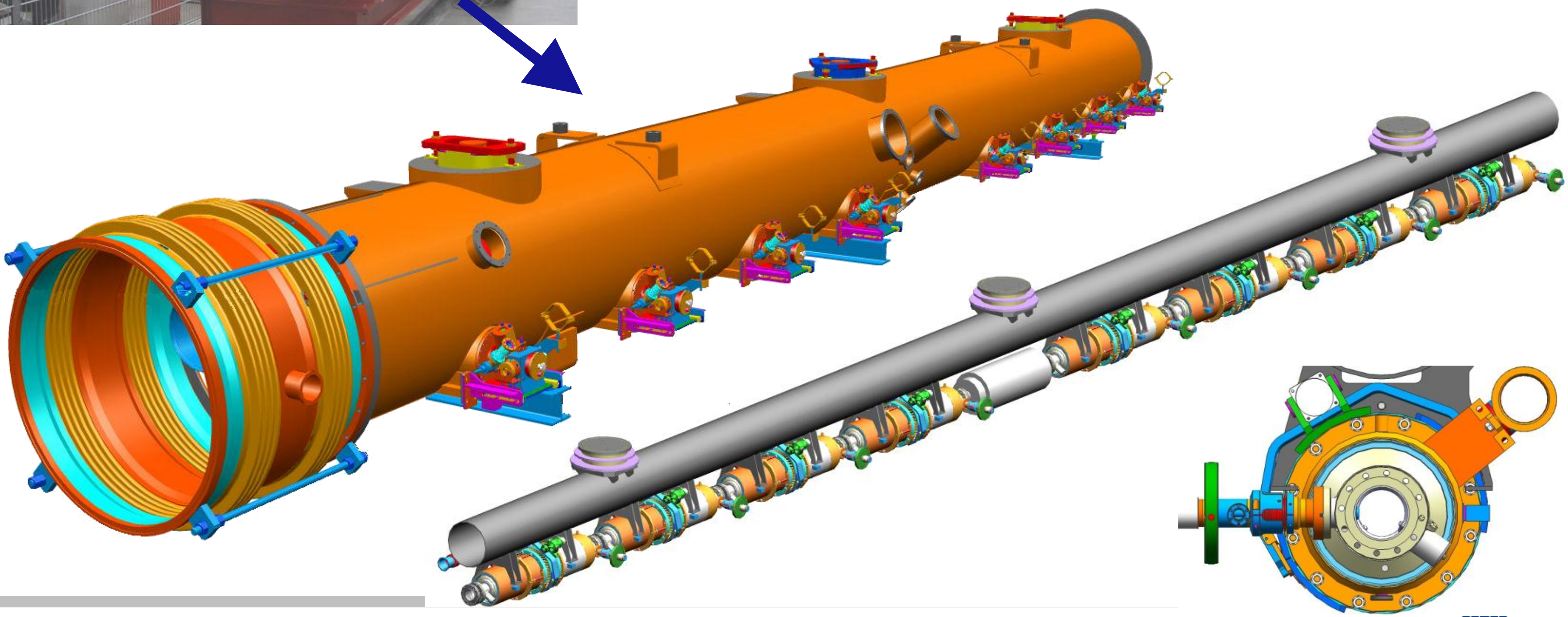
Detailed Cry 3 Cross Section



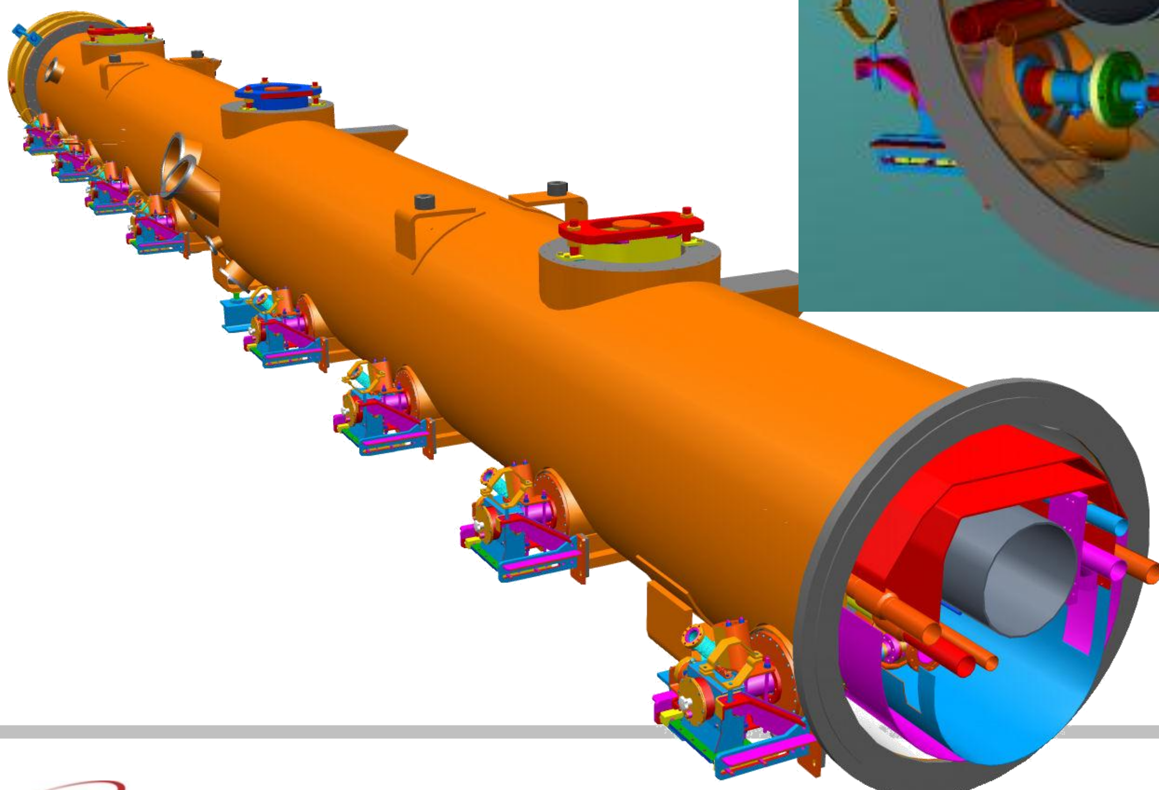
Towards ILC Cryomodule

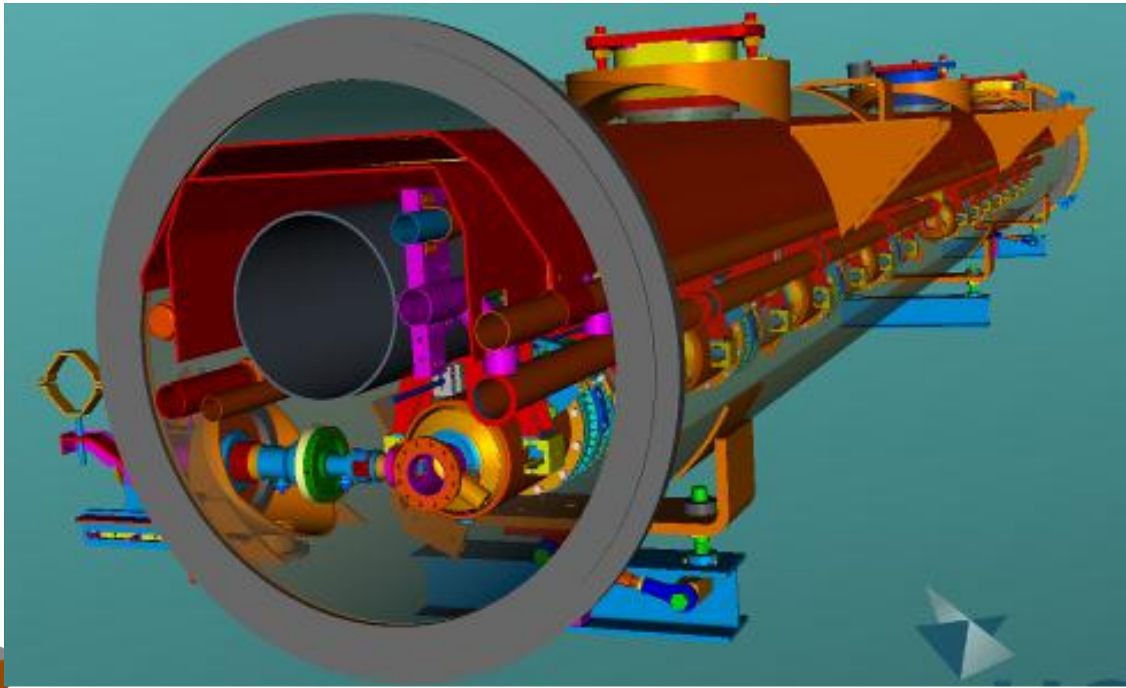


- International collaborative Effort in the three regions
- Design changes are towards nailing down slot length of components
  - Costing should be straight-forward from TTF (and possibly XFEL) experience



ILC Cryomodule: Conceptual Model





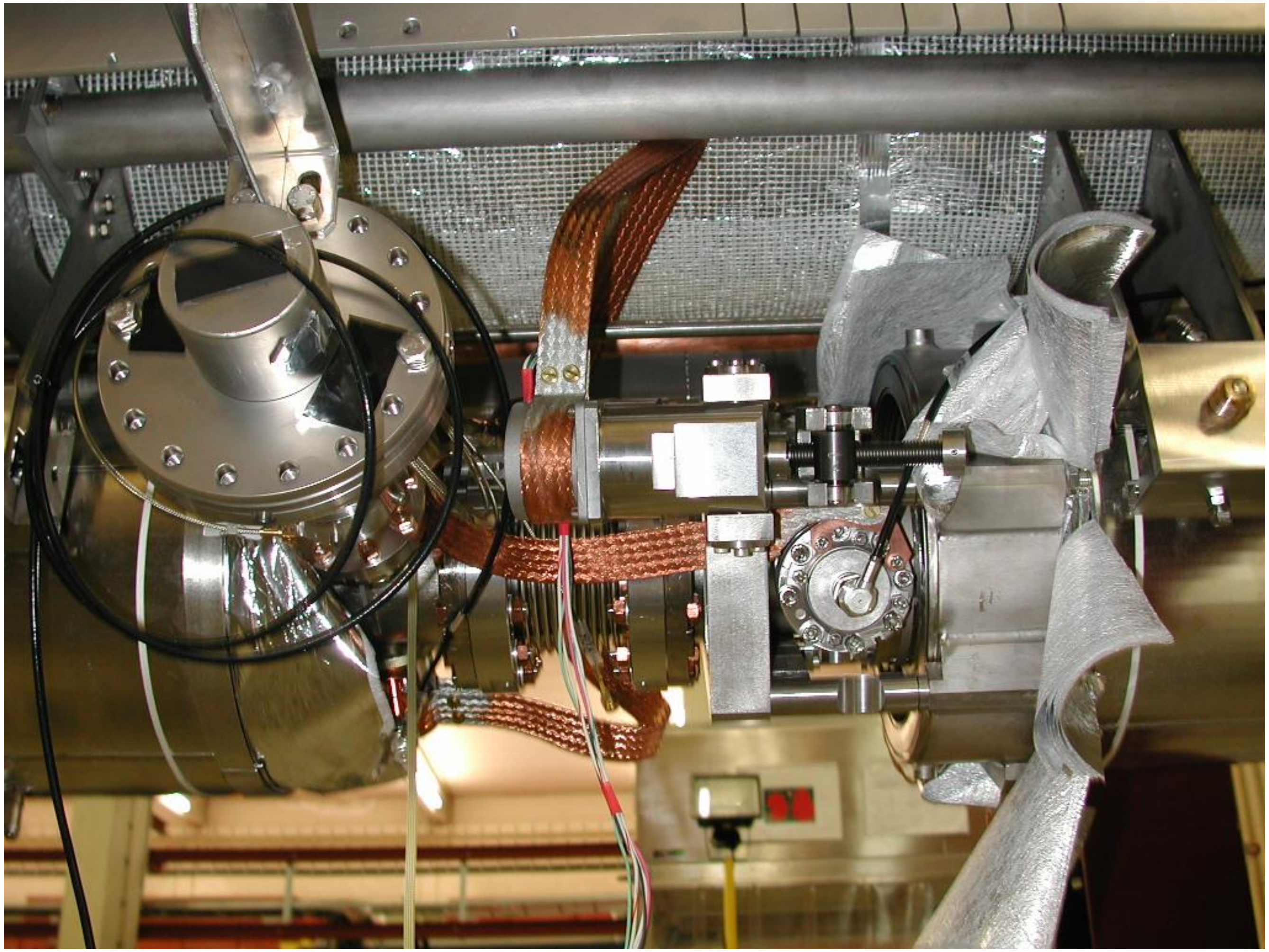
Module assembly picture gallery - 1

String inside the Clean Room

Module assembly picture gallery - 2

String in the assembly area

Module assembly picture gallery - 3



Cavity interconnection detail

Module assembly picture gallery - 4

String hanged to he HeGRP

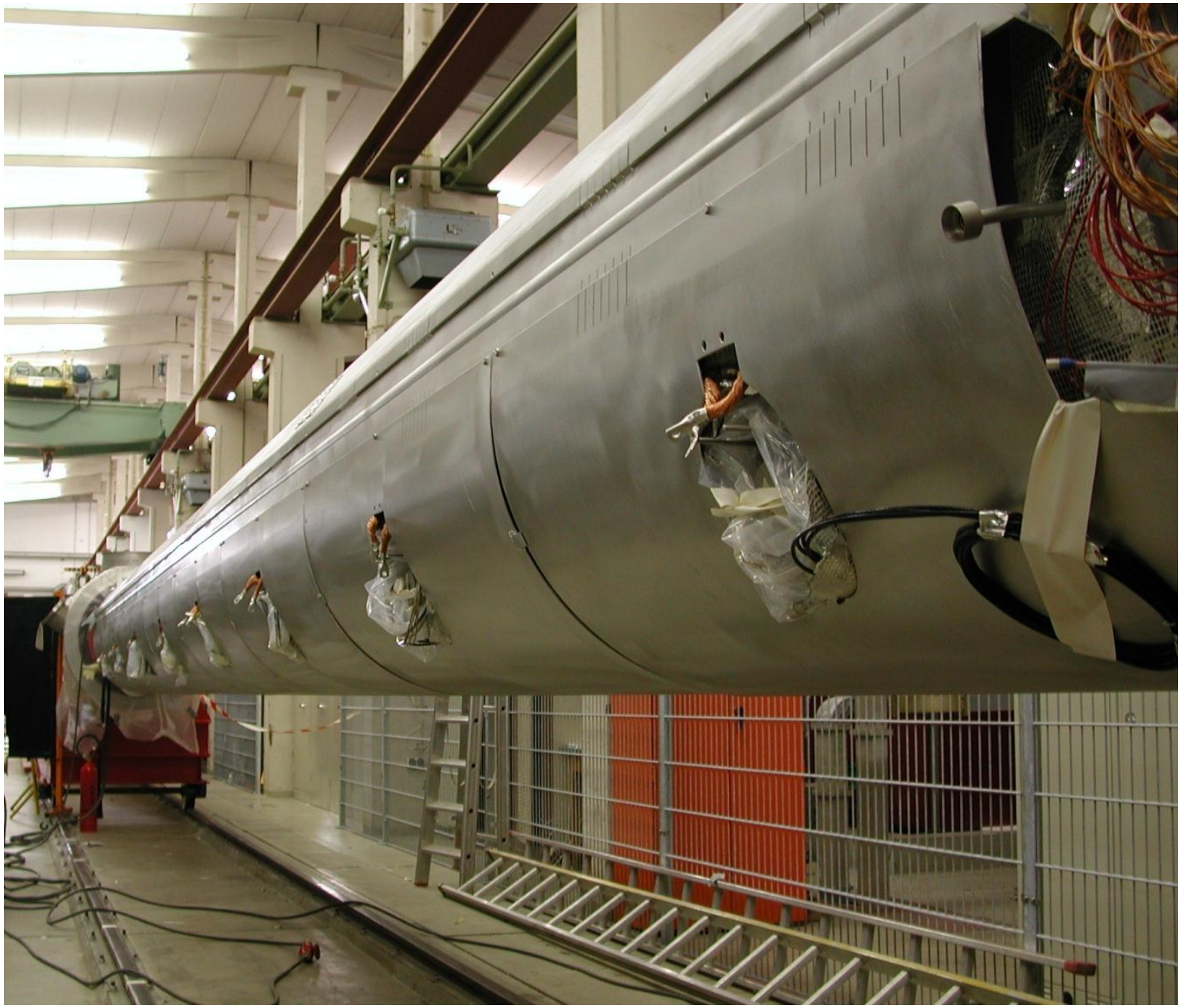
Module assembly picture gallery - 5

String on the cantilevers

Module assembly picture gallery - 6

Close internal shield MLI

Module assembly picture gallery - 7



External shield in place

Welding "Fingers"

Sliding VV on shield (MLI)

Module assembly picture gallery - 8

Complete module moved for storage

The Soleil Cryomodule

2.75 GeV, 500 mA Light Source

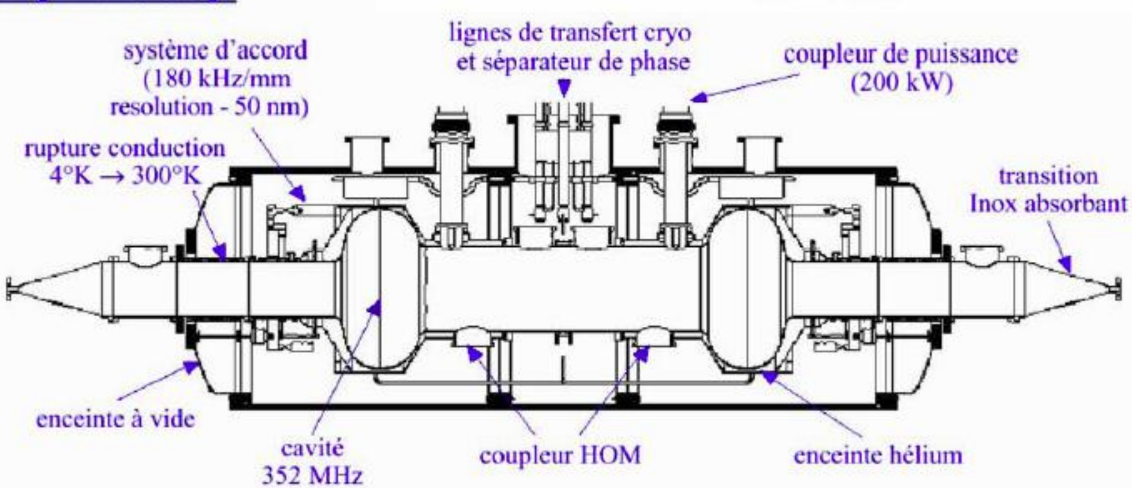
Design Parameters

- **Nb/Cu single-cell HOM damped cavities**
- **Designed and built by Saclay/CERN collaboration**
- **352 MHz**
- **2 two-cavity cryomodules**
- **1.2 MV/cavity**
- **LEP input couplers @ 200 kW**
- **loop HOM couplers**
- **Static heat loss 42 W**

High power test at CERN (12/1999):

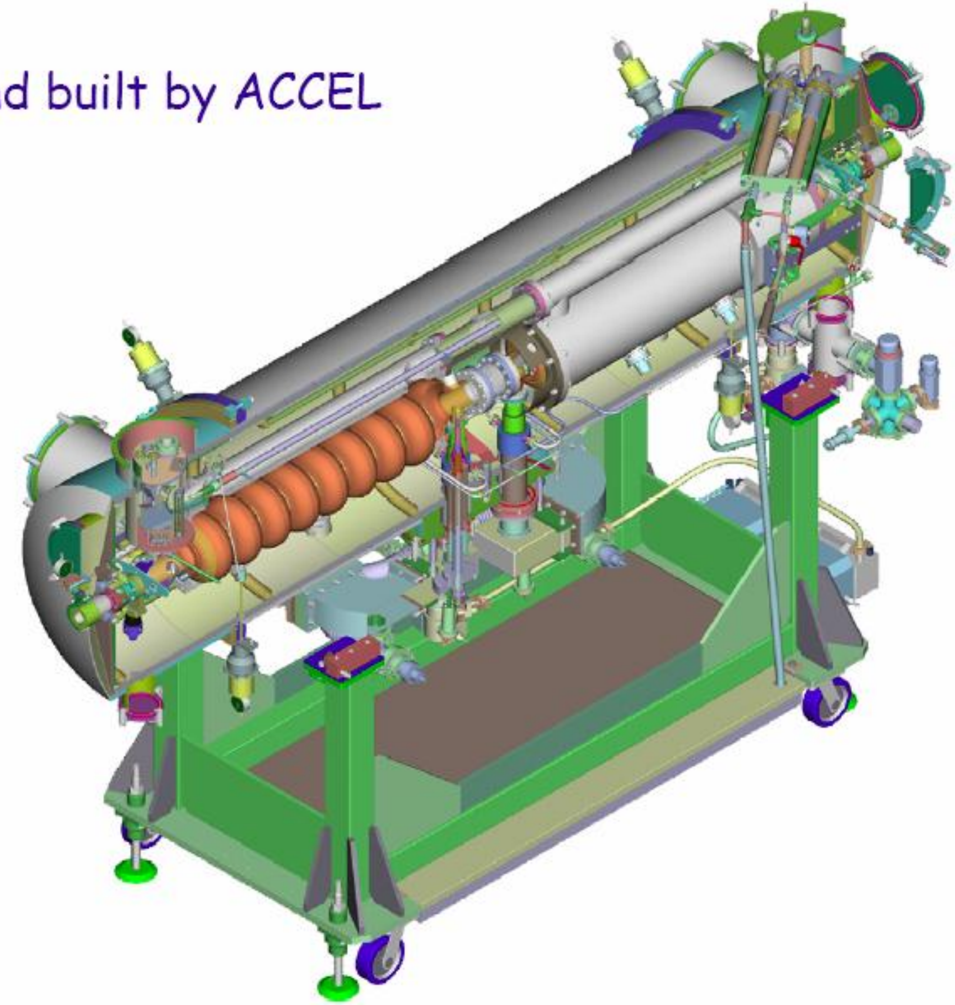
- **E_{acc} up to7 MV/m**
- **120 kW RF power**
- **20 W static heat leak**
- **Not optimal $Q_{ext,fund}$ of dipole HOM couplers**

Eacc (MV/m)



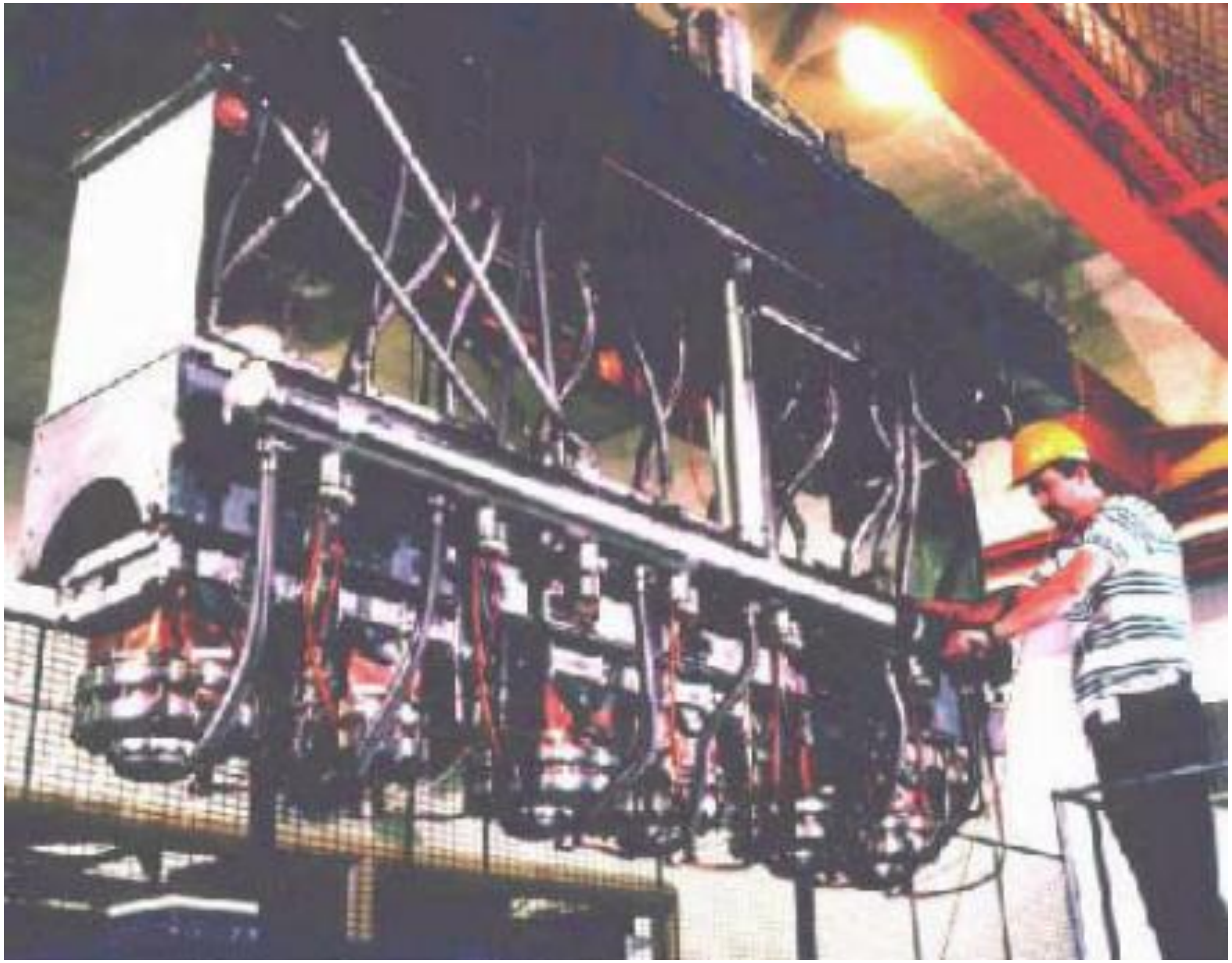
The Rossendorf Cryomodule

Designed and built by ACCEL



The CESR Cryomodule

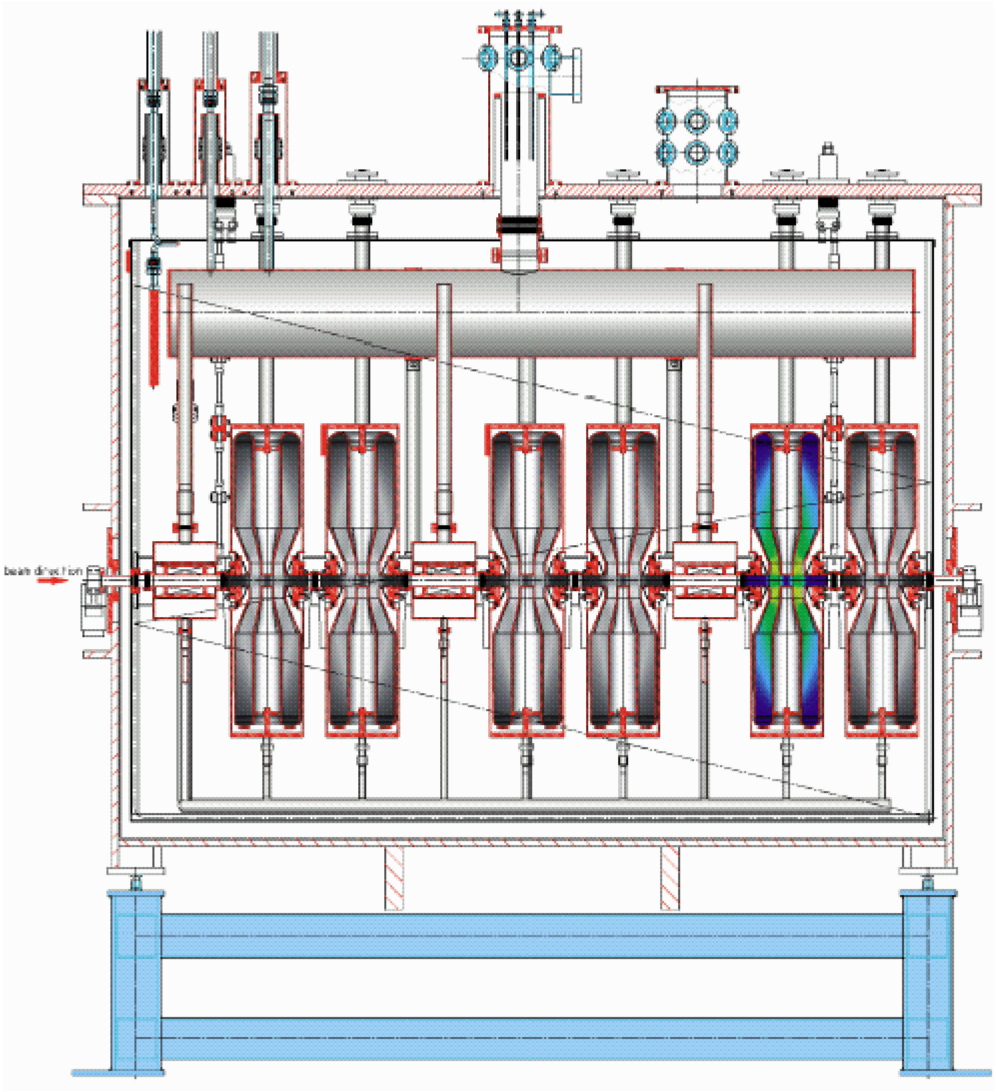
ATLAS - ANL



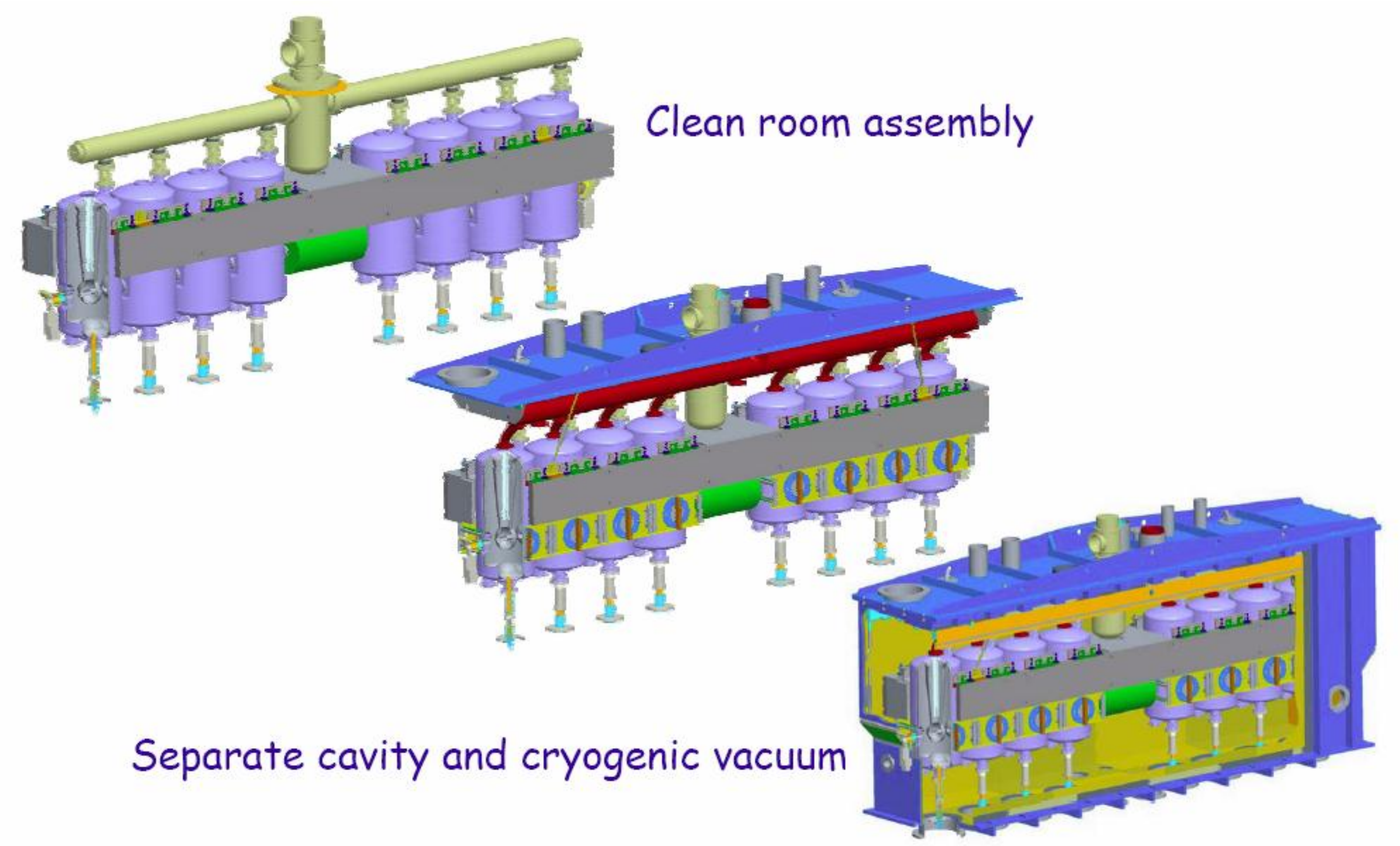
JAERI

ALPI - LNL

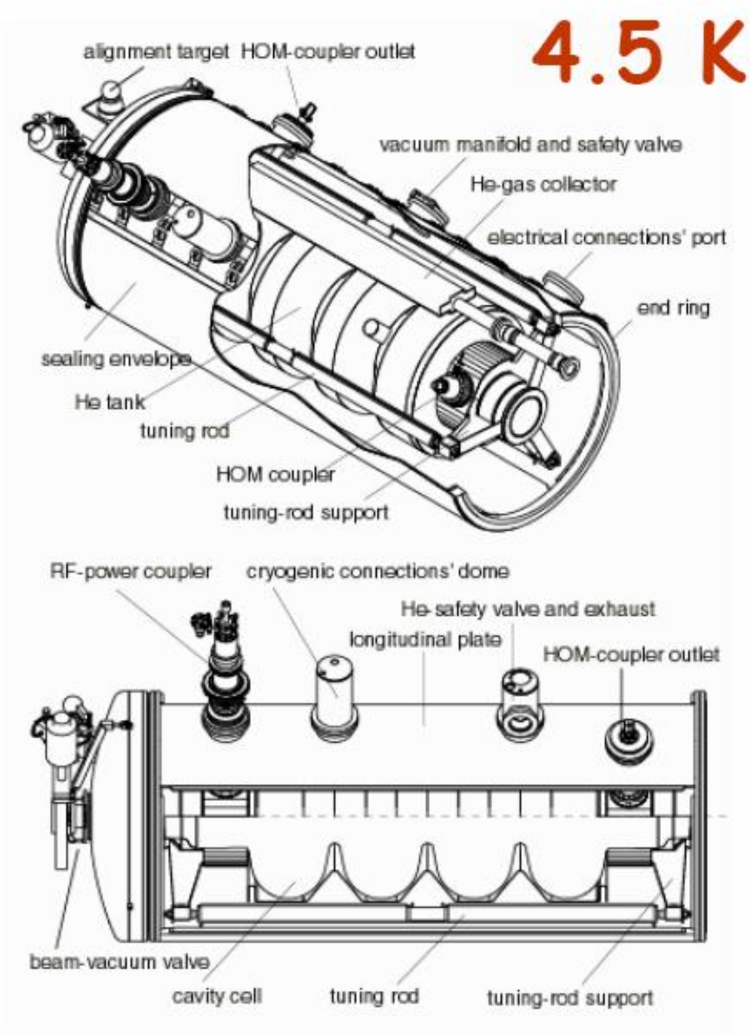
SARAF (Accel)



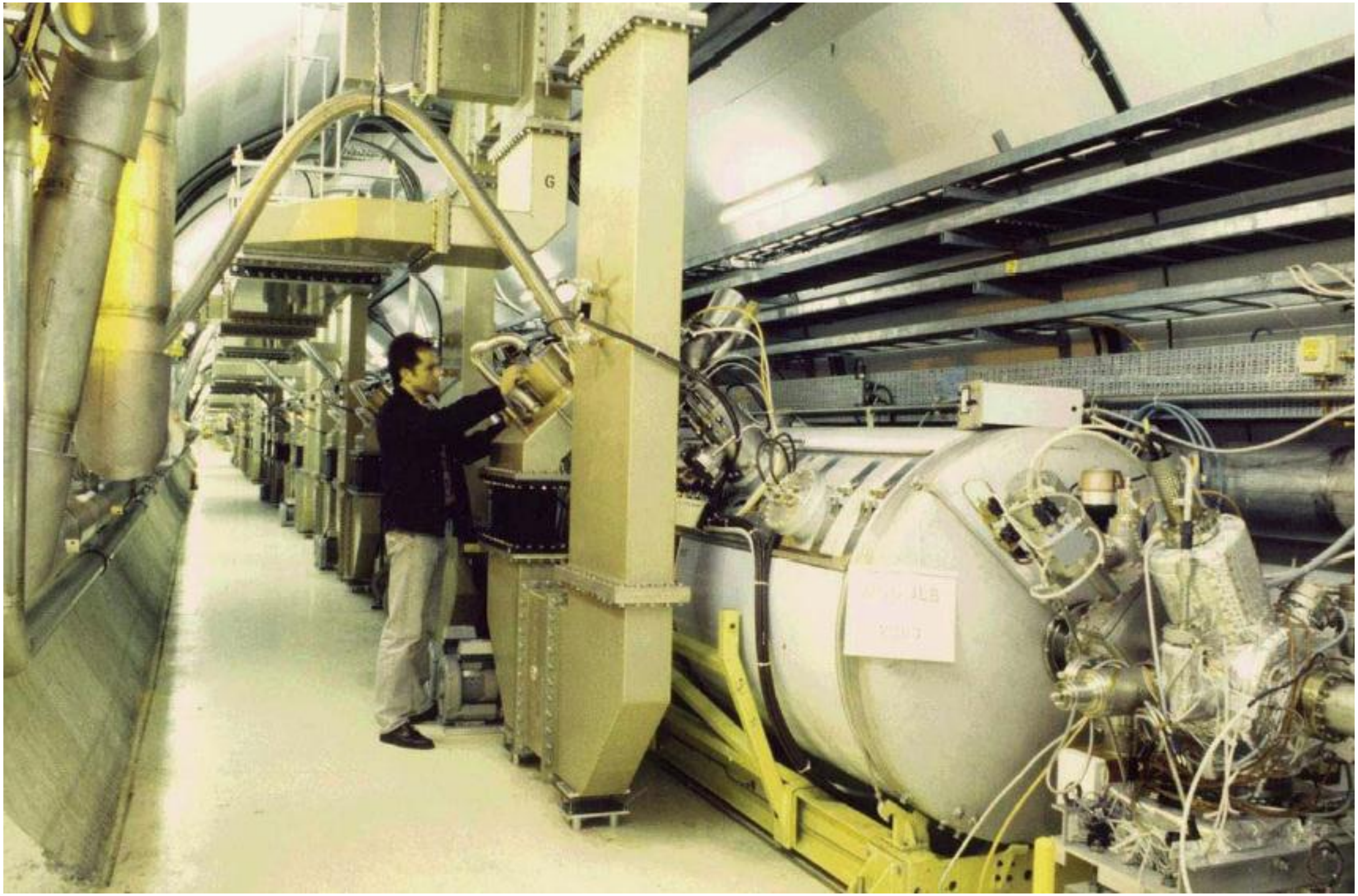
ANL



LEP II


4.5 K
alignment target
HOM-coupler outlet
vacuum manifold and safety valve
He-gas collector
electrical connections' port
end ring
sealing envelope
He tank
tuning rod
HOM coupler
tuning-rod support
RF-power coupler
cryogenic connections' dome
He safety valve and exhaust
longitudinal plate
HOM-coupler outlet
beam-vacuum valve
cavity cell
tuning rod
tuning-rod support

LEP II



HERA