Test Stand Design for magnets and SRF cavities

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Outline

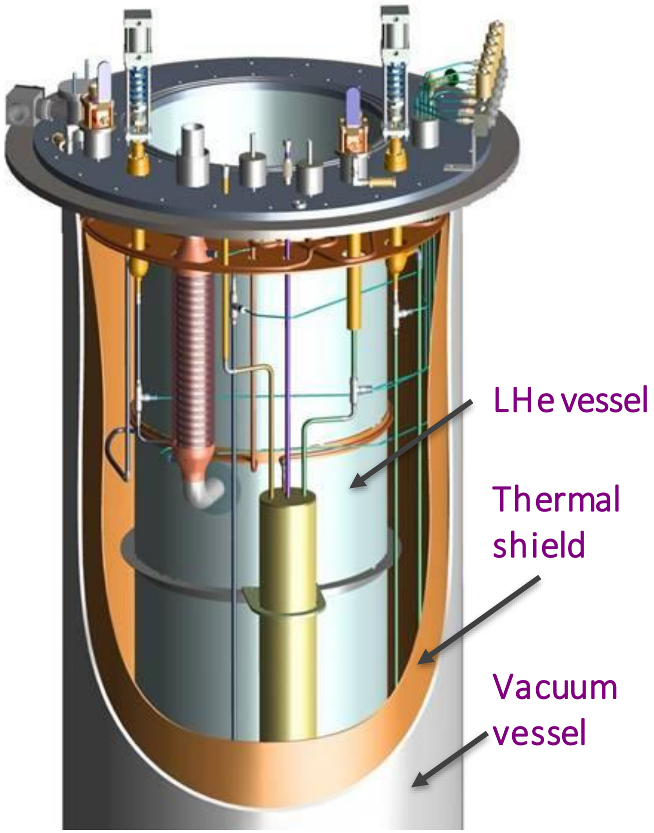
- Test dewars and test stands for SRF cavities and magnets
  - Vertical test stands
    - Saturated bath test dewars
    - Double bath test dewars
  - Horizontal test stands
  - Horizontal 'vertical' test stand
  - Cryogen free test stand
- Procurement and operations

Saturated *vs.* subcooled helium bath

- Accelerator magnets are often cooled with subcooled liquid
  - Typically working near the limit of the superconductor with large stored energy
  - Ensure complete liquid coverage and penetration
- Superconducting RF cavities are generally cooled with a saturated bath
  - Large surface heat transfer in pool boiling for local hot spots
  - Very stable pressures, avoid impact pressure variation on cavity tune
- Magnet and SRF test stands are designed accordingly

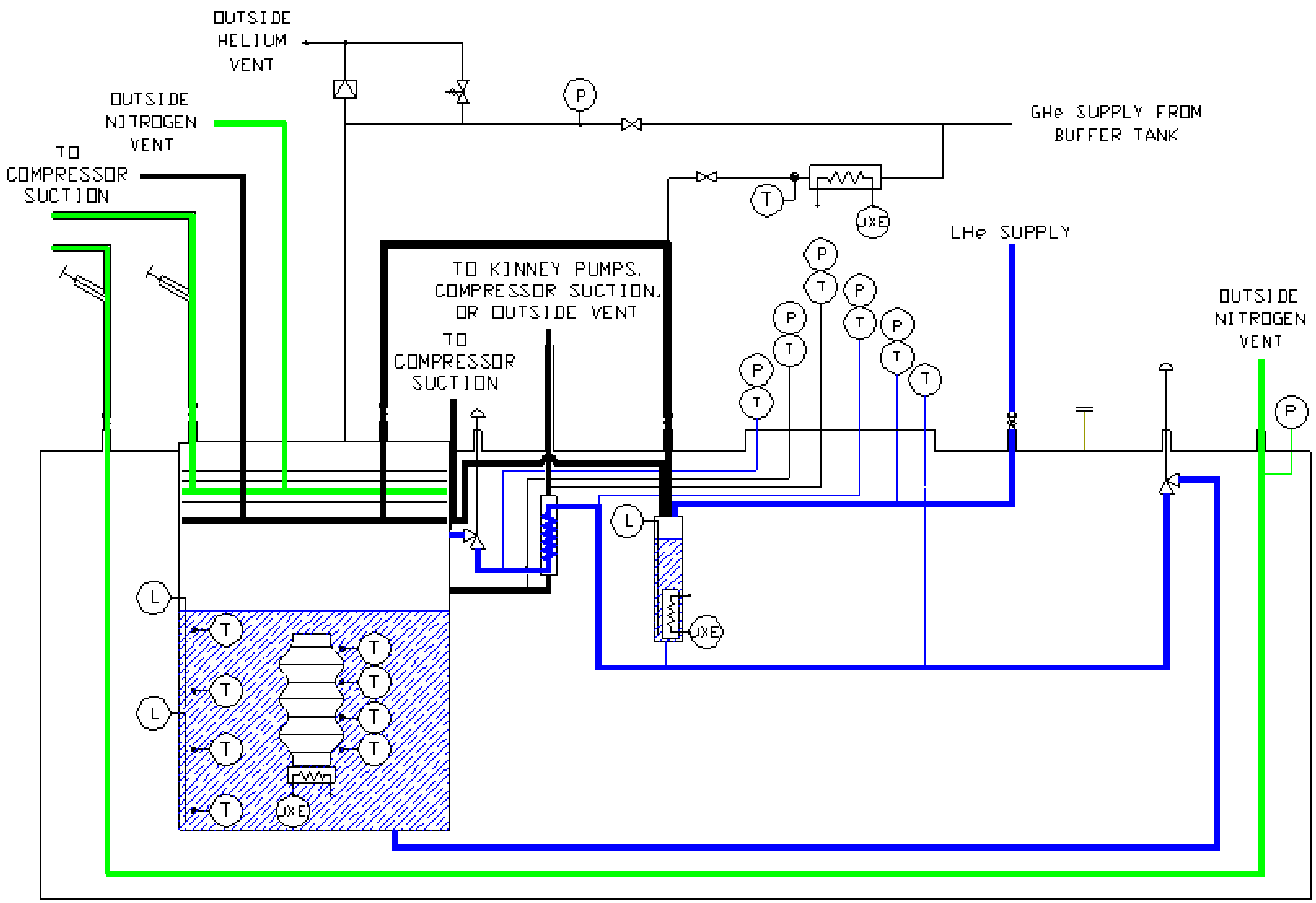
Saturated bath dewar

- Simple, in principle
  - Essentially a “bucket” of liquid helium
- Entirely at saturation pressure
- Very stable pressure and temperature
- Low heat load due to simple “hanging” construction of LHe vessel



CAD rendering of SRF cavity vertical test stand (VTS) at Fermilab

Saturated bath dewar



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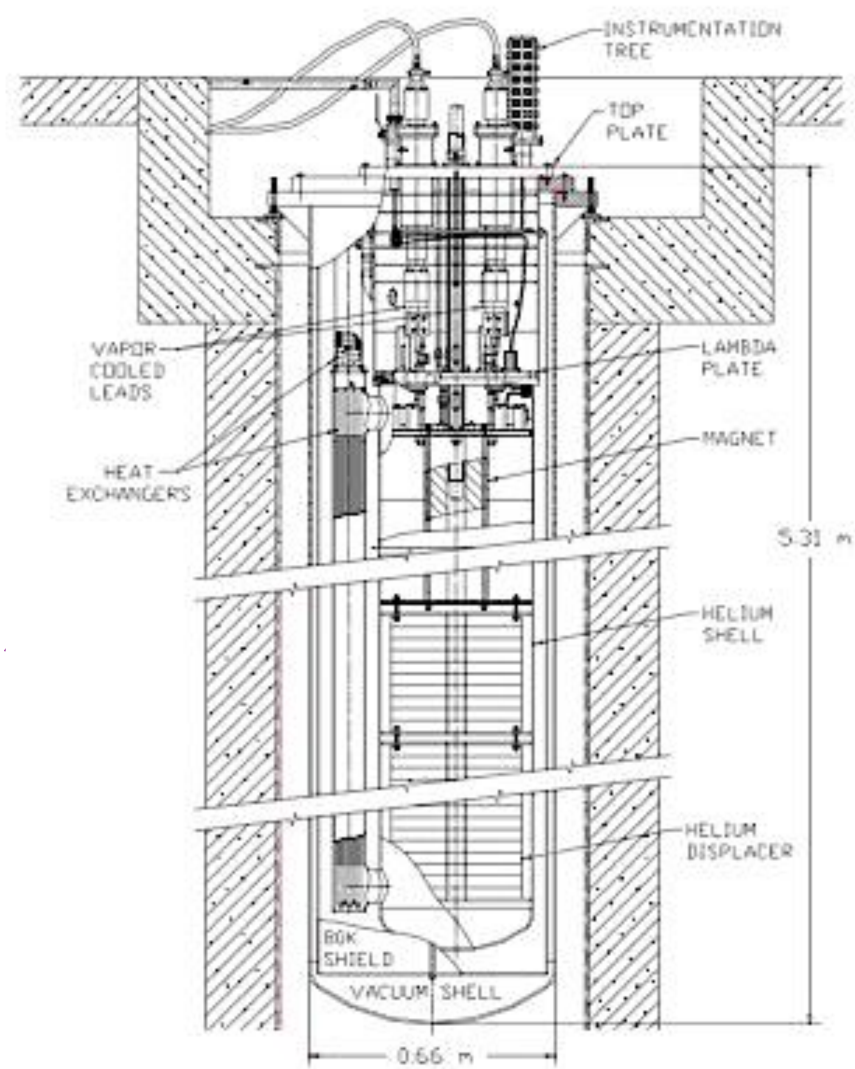
Saturated bath dewar – some issues

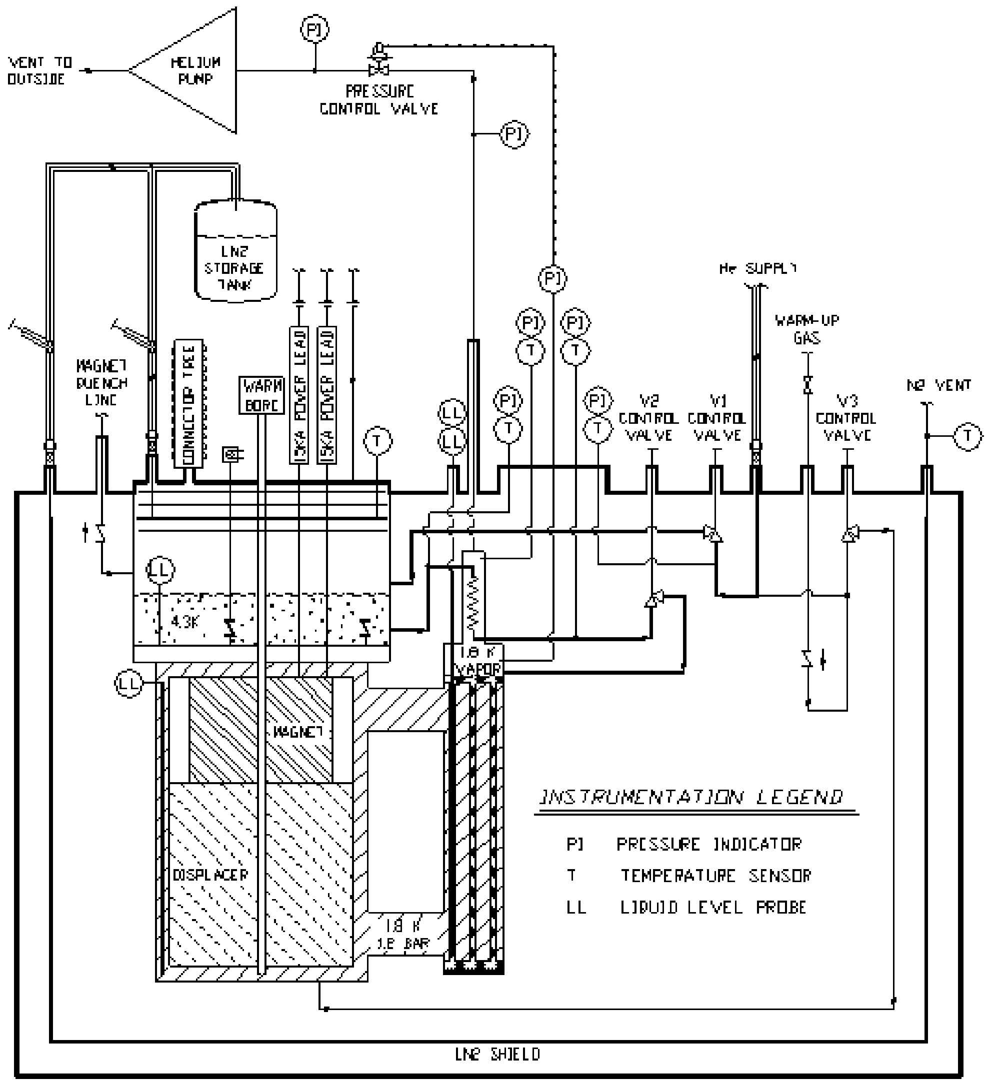
- Sub-atmospheric for temperatures below 4.2 K
  - Many potential air inleaks
  - Air inleak may appear as operational problem without a clear cause
    - For example, low pump-down or cool-down rate
- Large volume of liquid presents venting problem with loss of insulating vacuum to air
  - As much as 4 W/cm^2 heat deposition on bare surface
  - Venting may be a design challenge for a low-pressure vessel (large pipes, etc.)
  - We use MLI even under a thermal shield in order to reduce venting flow rate with loss of vacuum

Double bath dewar

- Saturated 4.4 K liquid above 1.2 bar, 2 K liquid
  - 2 K liquid is subcooled, single phase liquid
  - Separated by a ‘lambda plate’
- Lower heat load to 2 K



Double bath dewar



- Large, vertically oriented heat exchanger between saturated bath and pressurized helium permits operation with normal, subcooled helium as well as superfluid

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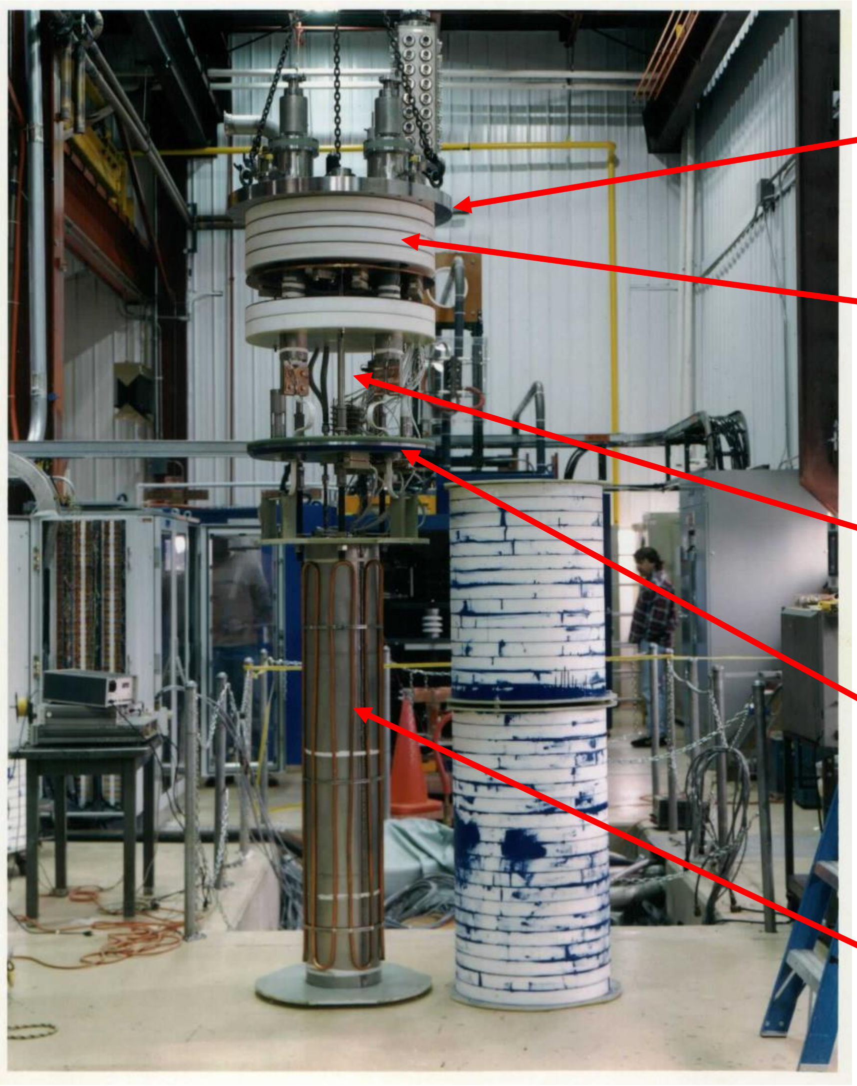
Double bath dewar



Double bath dewar for magnet test at Fermilab

Top plate

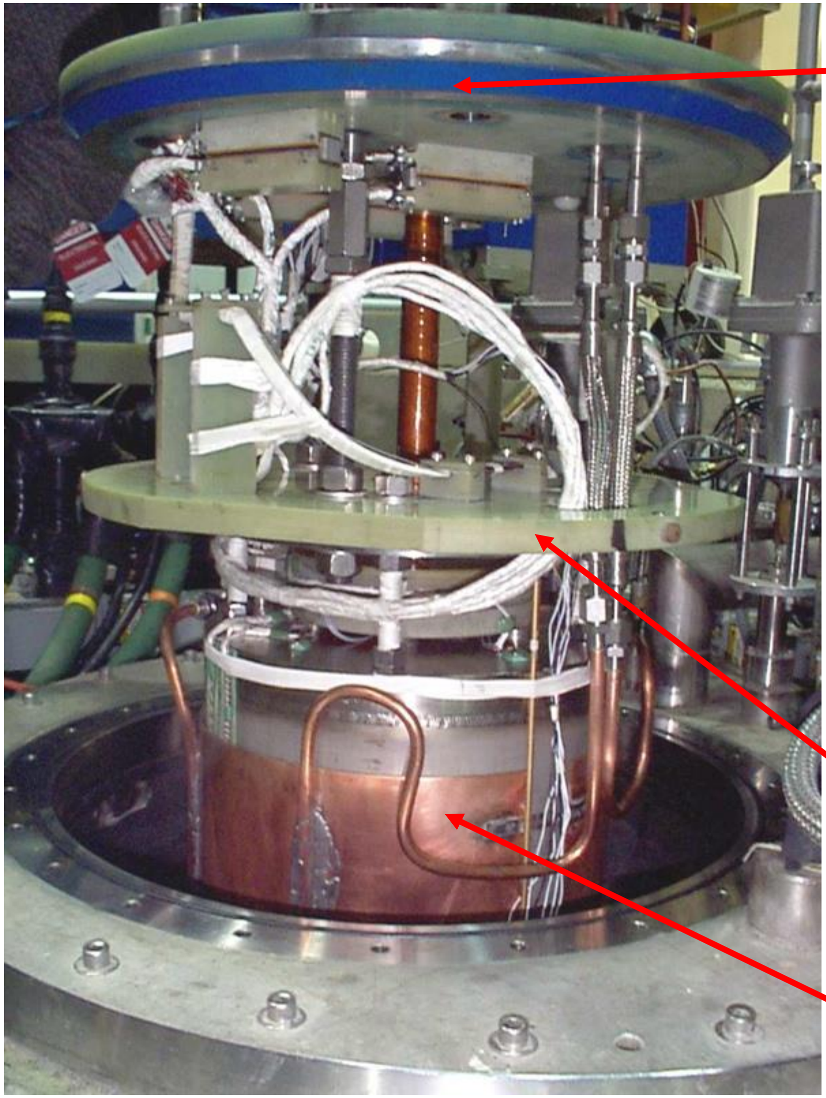
Closed-foam (Rohacel) insulation

4.4 K vapor space

Lambda plate

Magnet

Double bath dewar



Double bath dewar for magnet test at Fermilab

Lambda plate and seal (blue)

- Need not be hermetically tight
- Key feature is to provide long, thin path for heat transport, so leaks should be long
- Flat seal rather than "knife-edge"

Intermediate support plate

Copper cladding around magnet (for cooldown)

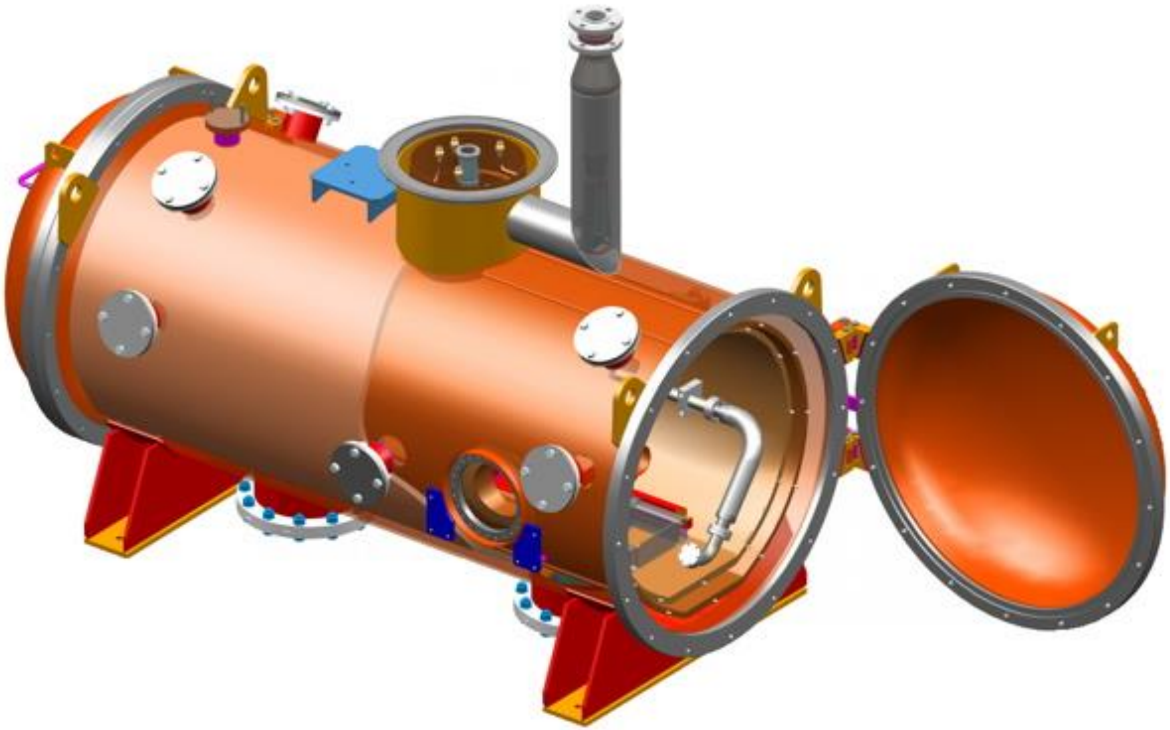
Double bath dewar – some issues

- Less amount of superfluid than a saturated bath dewar
  - Need to be more aware of heat leaks
- Heat transport via a "lambda" seal between normal and superfluid is a problem
  - Seal must be tight with long leak paths
  - Heat loads come from various sources, so difficult to distinguish lambda seal leak from others

Horizontal test stands

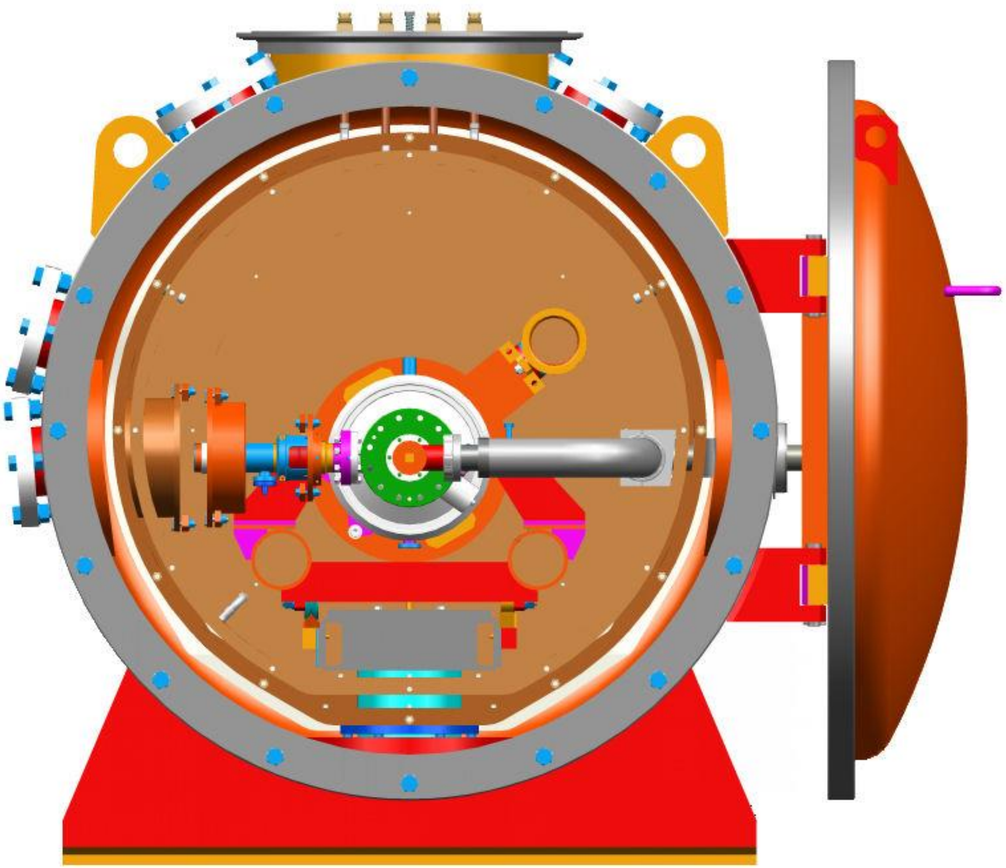
- Horizontal -- simply as opposed to vertical orientation of a long magnet or SRF cavity in a typically vertically oriented dewar
- May consist of just end boxes
  - A supply box for power and cryogens
  - A turnaround box
  - Test object in its own cryostat
  - Interconnects to the end boxes
- Or may be more like a horizontal vacuum chamber or horizontally oriented dewar
- Like vertical test dewars, may provide saturated bath or subcooled liquid

SRF cavity test stand



- CAD rendering of vacuum chamber for SRF cavity tests at Fermilab
- Designed for tests of RF cavities which are pre-installed into helium vessels

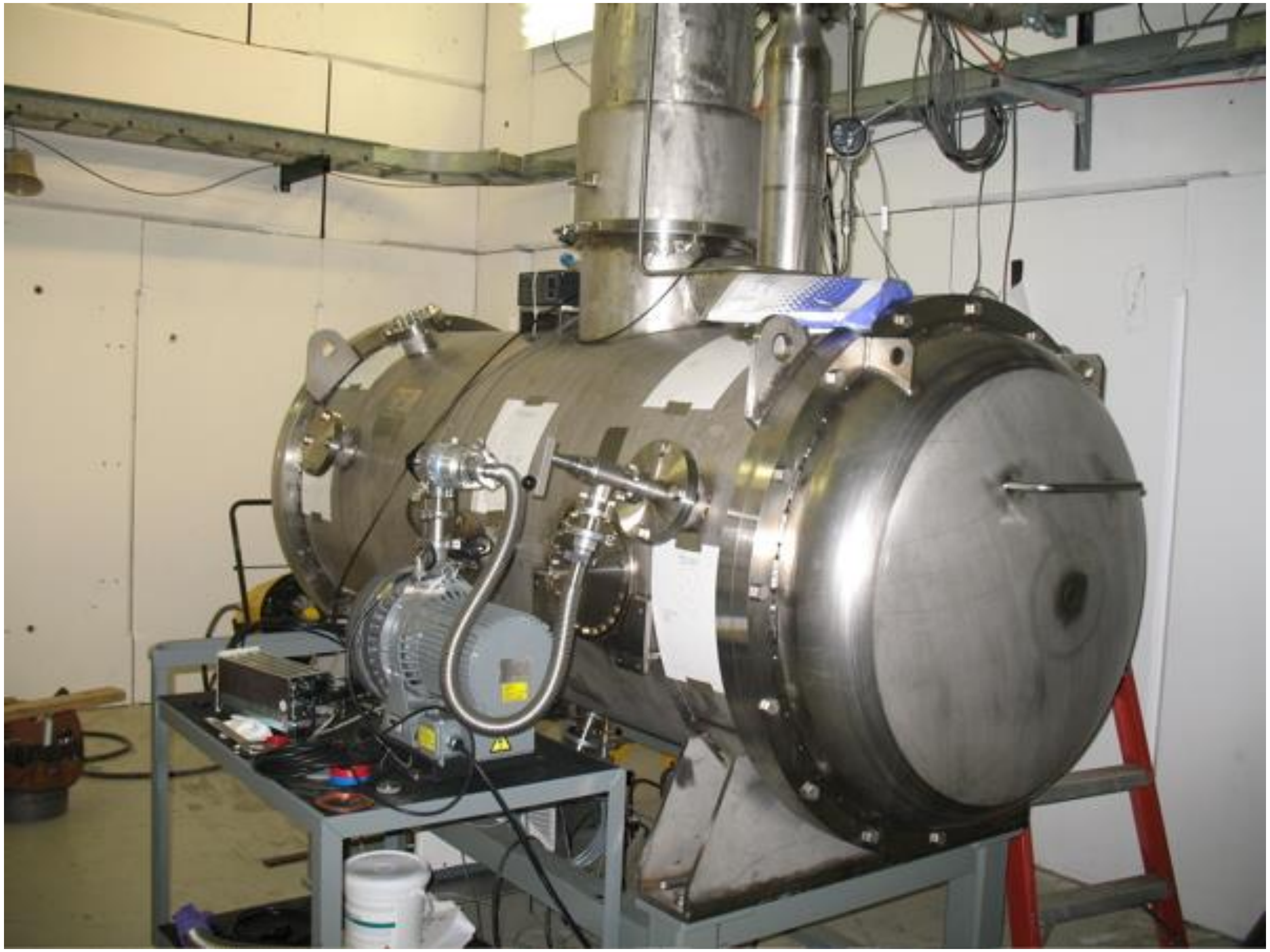
SRF cavity test stand



Cavity loading end view of SRF HTS

Helium vessel with RF cavity slides in, then cryo pipes and RF coupler connected

SRF cavity test stand



Fermilab SRF cavity test cryostat

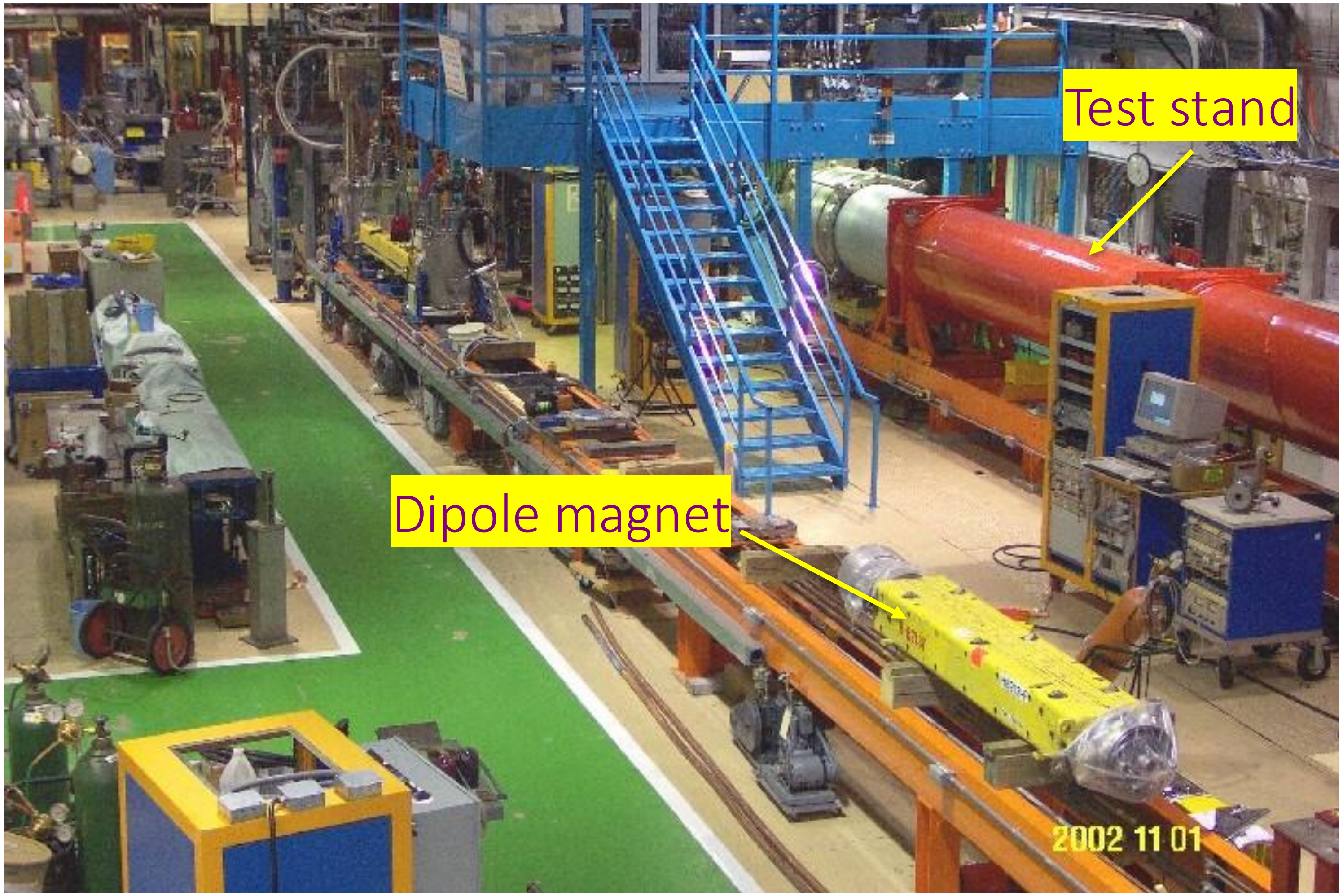
- Stainless vacuum shell
- Rubber O-ring seals vacuum door
- Copper thermal shields
- Cryogenic piping in top
- Indium metal seals connect cryogenic piping

Providing 2 K on a test stand

- Test stand refrigeration requirements are typically small
  - A large, 2 K cryoplant will not be available
  - 4.5 K helium from either a small liquefier or storage dewars will provide refrigeration
  - Room-temperature vacuum pumps provide the low pressure for the low temperature helium (below 4.2 K)
  - Small heat exchangers may be incorporated for continuous fill duty

Horizontal test stand for magnets

Magnet test stand 5 at Fermilab



Horizontal test stand for magnets

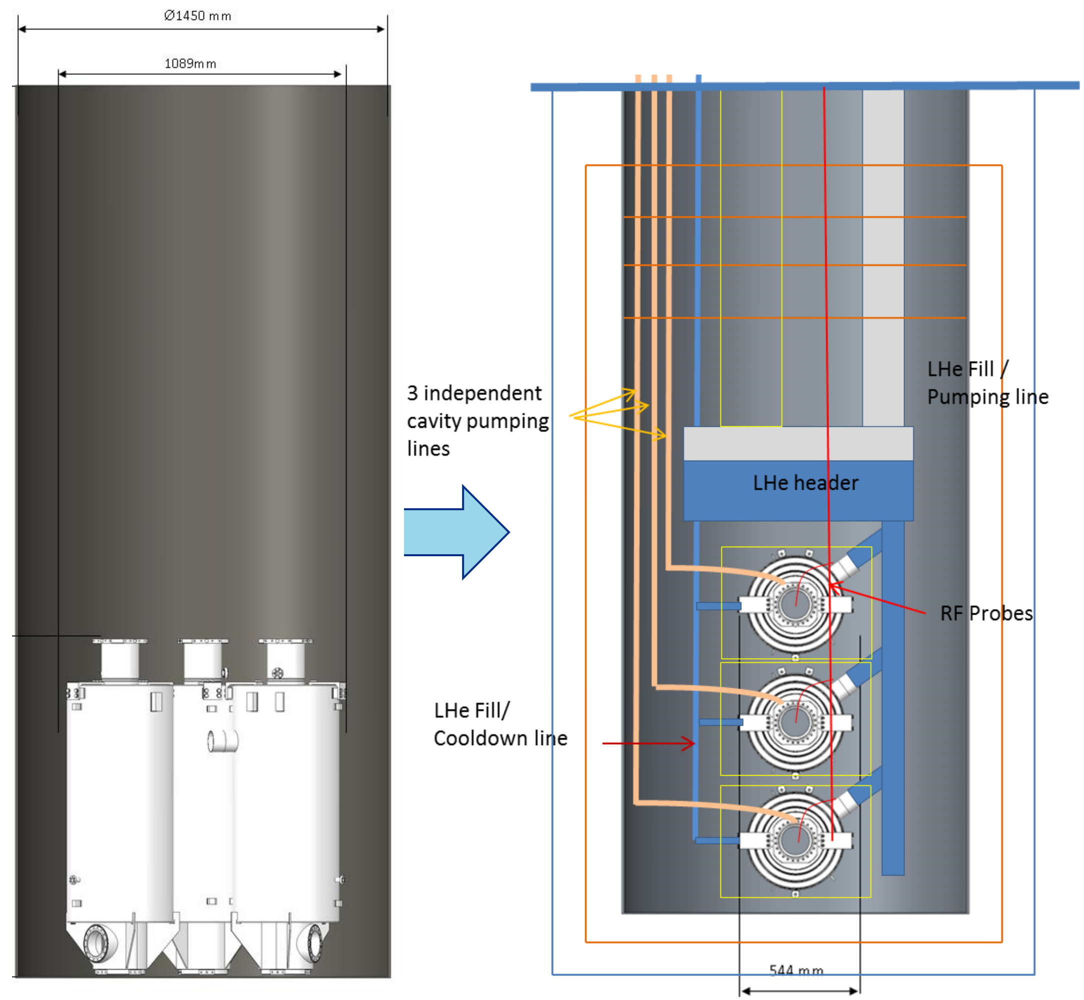
Magnet test stand 5 at Fermilab

- Fermilab's first superfluid magnet test stand at commissioned in the 1980's
- Provided stagnant or forced flow operation
  – Liquid helium 4.5 K to 1.8 K
- Illustrates use of local test stand heat exchangers in combination with large warm vacuum pumps to provide superfluid helium

“Horizontal” VTS at STFC Daresbury

2 K RF testing of ESS high-β cavities in a conventional bulk LHe bath cryostat would require **~7500 L LHe** per test and GHe handling for ~**20 g/s**

Instead, developed a VTF that tests 3x jacketed cavities (~50 L each) mounted horizontally and connected to common header tank (~200 L) and fill/pumping line requiring **~1500 L** per test with **<2 g/s** in steady state under static load



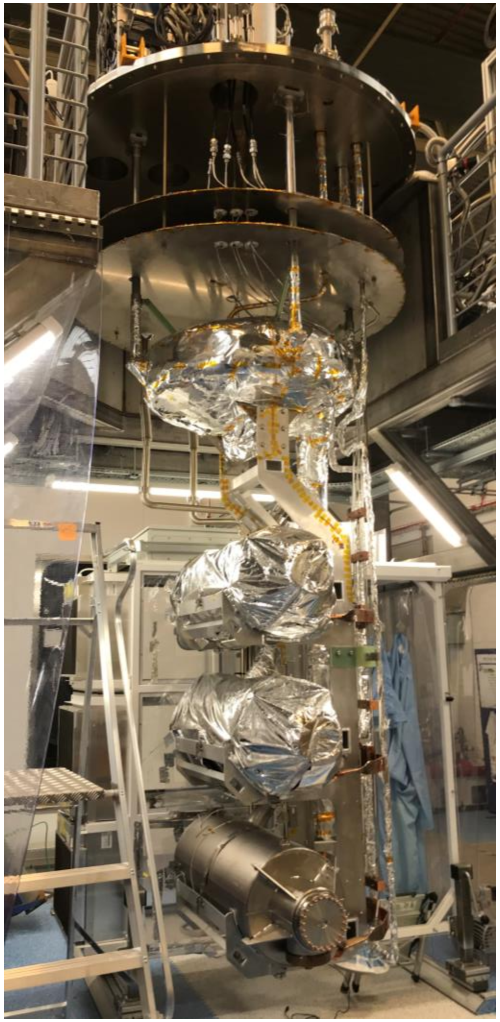
"Horizontal" VTS at STFC Daresbury

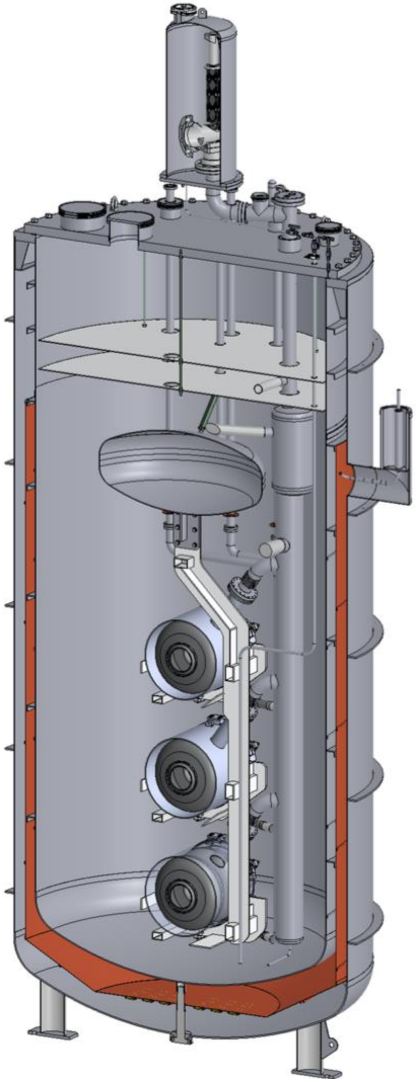
Pair of identical inserts with common cryostat (OVC and IVC, thermal shielding, magnetic shielding) to allow simultaneous testing and preparation of next set of cavities

Air Liquide Helial ML cryoplant provides ~130 L LHe/hour and ~2 g/s GHe at 50 K

2 K pumps providing >1 g/s @ 30 mbar (2 K) with additional capacity to be installed 2021

Recovery circuit => closed-cycle





Cryogen-free test stand

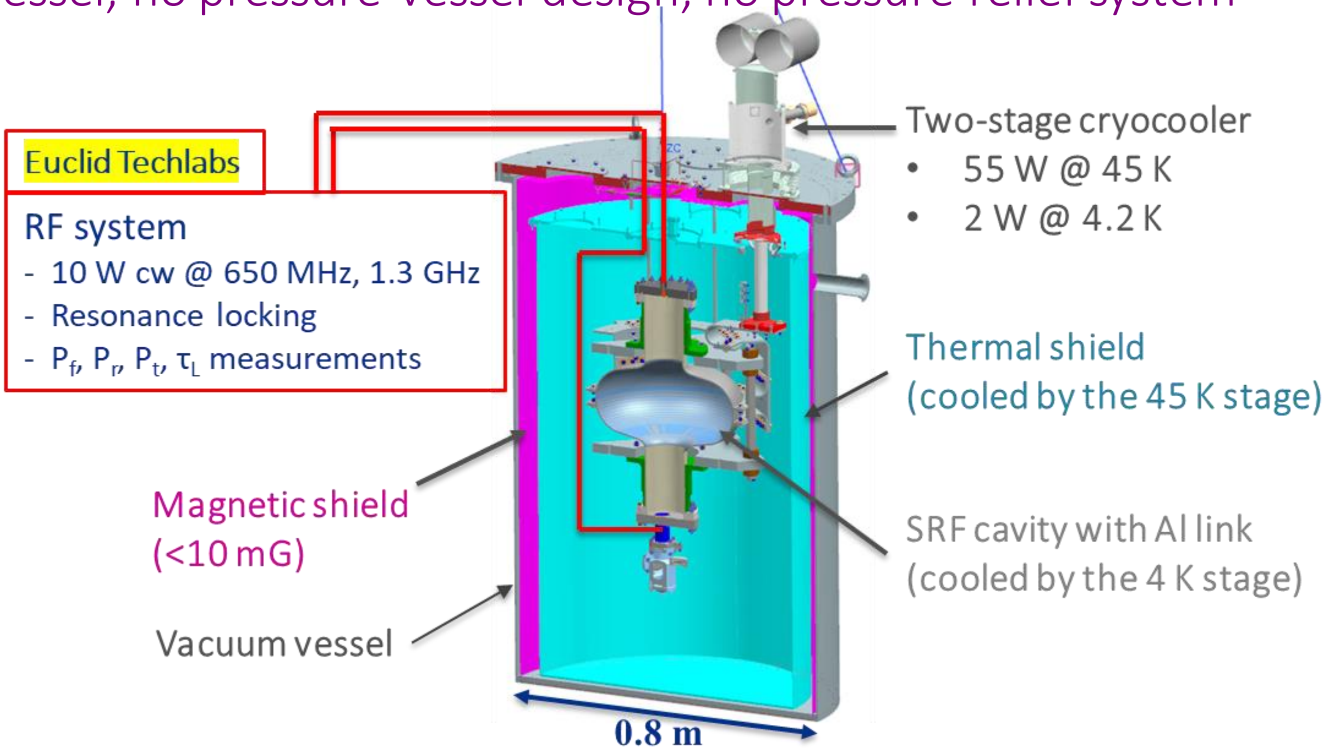
4 K cooling is provided by a pulse tube cryocooler

- Capacity limited to a few Watts @ 4 K (depending on number of cryocoolers),
- Testing limited to single cell high Q_0 cavities at gradients up to ~10 MV/m

Advantages

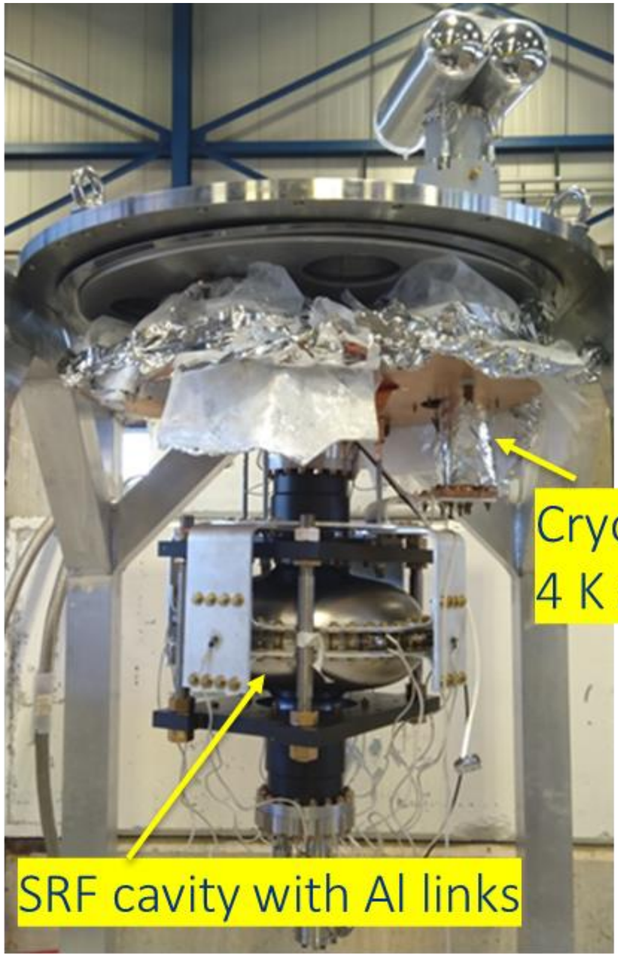
- Simple vacuum vessel, no pressure-vessel design, no pressure relief system

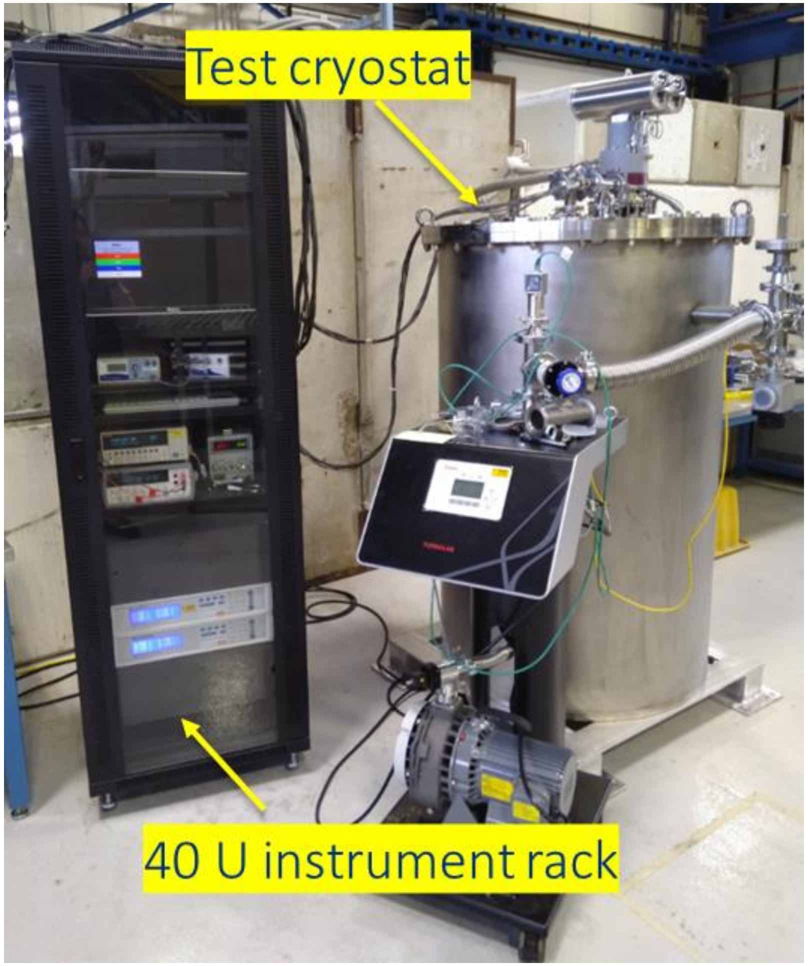
4 K cryogen-free test stand at Fermilab



Cryogen-free test stand

4 K cryogen-free test stand at Fermilab





Procurement strategies

- Design and build in-house
- Design and procure "to print"
- Detail interfaces and critical areas but not entire object -- procure to specs and drawings
- Performance specification with only a few key interfaces detailed

Procurement strategies

- Test vessels and stands with end boxes are typically unique -- one or a few-of-a-kind
- Industry is small and specialized
- Designs often contain new, risky, or erroneous features
- Close collaboration with a vendor is critical
  - Frequent (once per week or more) inspections and meetings at the vendor

Design, procurement, installation timescales

- Design of a new cryogenic box
  - 0.5 or more man-years engineering
  - 1.0 or more man-years drafting
  - Typically 6 - 9 months calendar time
- Procurement -- another 6 - 12 months
- Installation
  - Complexity of instrumentation, controls, interfaces are often underestimated
  - Several months
- Result -- two years or more

Operations

- Common problems encountered
  - Warm gas in adds large amount of heat
    - A very small leak via a valve isolating warmer helium from the lower temperature system may be a hidden source of heat
    - 1 mg/sec at 300 K ==> 1.5 Watts to 4.5 K!
  - Air leak in (contamination)
    - Sub-atmospheric operation for <4.2 K provides risk of air inleaks, especially through instrumentation and other seals

More on operations

- Instrumentation
  - *In situ* checks like at a phase change can provide verification of temperatures and pressures
  - We generally allow a period of "thermal studies" upon startup of a new test system
    - Check instrumentation
    - Review operating procedures
    - Verify thermal performance

Content courtesy

- Tom Peterson of SLAC, USA
  - For much of the material on VTS and HTS test stand
- Andrew May of STFC Daresbury, UK
  - For material on horizontal VTS at STFC Daresbury

References and further reading

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