Cryogenic Distribution

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January, 2017

Cryogenic distribution

- This portion of the class will focus on certain topics in the design and fabrication of distribution equipment for large cryogenic systems
  - Transfer lines
  - Feed and distribution boxes

Distribution function

- These devices serve as the interface from a cryogenic plant to specialized cryogenic equipment.
- Such cryogenic "boxes" may include
  - Thermal transitions of various kinds
  - Power leads for electric current
  - Instrumentation
  - Vacuum barriers
  - Control valves, relief valves, etc.

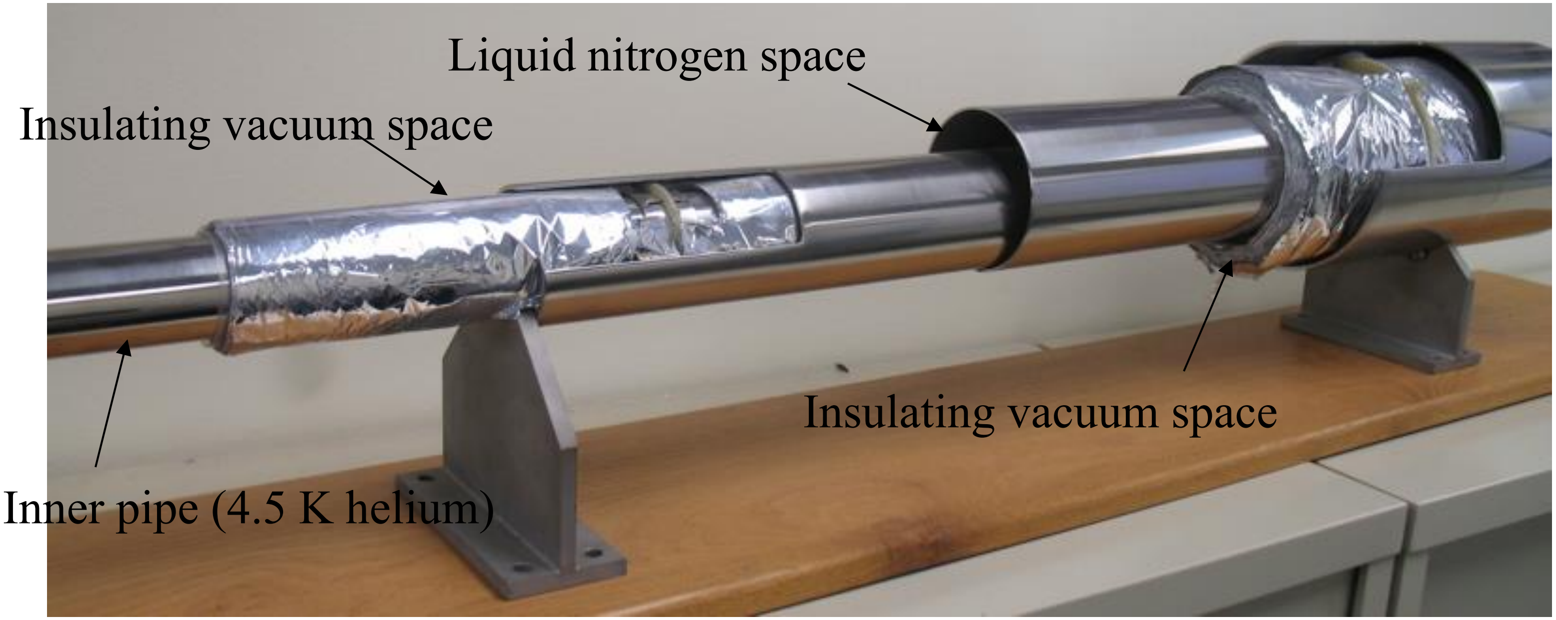
Outline
Cryogenic distribution

- Transfer lines
- Vacuum barriers
- Lambda plugs
- Feed and distribution boxes
- LCLS-II distribution system overview

Cryogenic transfer lines

- Techniques have become fairly standard
- Stainless vacuum pipe
- Stainless (or sometimes copper) inner lines
- Plastic or composite material (e.g., G-11 epoxy-fiberglass) supports

Fermilab's 4.5 K transfer line



- Supplies 4.5 K, supercritical (3 bar) helium over 6 km to "satellite" refrigerators
- Also provides LN2

Fermilab’s 4.5 K transfer line

- Outside on top of the accelerator enclosure, a full 6 km circumference ring
- Here a bypass around a building

Common transfer line issues

- Long lengths mean many welds
  - Leak checking may be a challenge
  - Division of insulating vacuum into manageable sections
- Thermal contraction allowance
  - Bellows and flexible hose, quality control issues
  - Different lines may shrink or expand first
- Inner line supports
  - Wear or bind with frequent thermal cycles
  - May involve use of plastics, requiring use of proper materials to avoid brittle failures

DESY TTF transfer line - 1

- 4.5 K and thermal shield flow from HERA cryo-plants to TTF

DESY TTF transfer line - 2

- 4.5 K and thermal shield flow from HERA cryo-plants to TTF

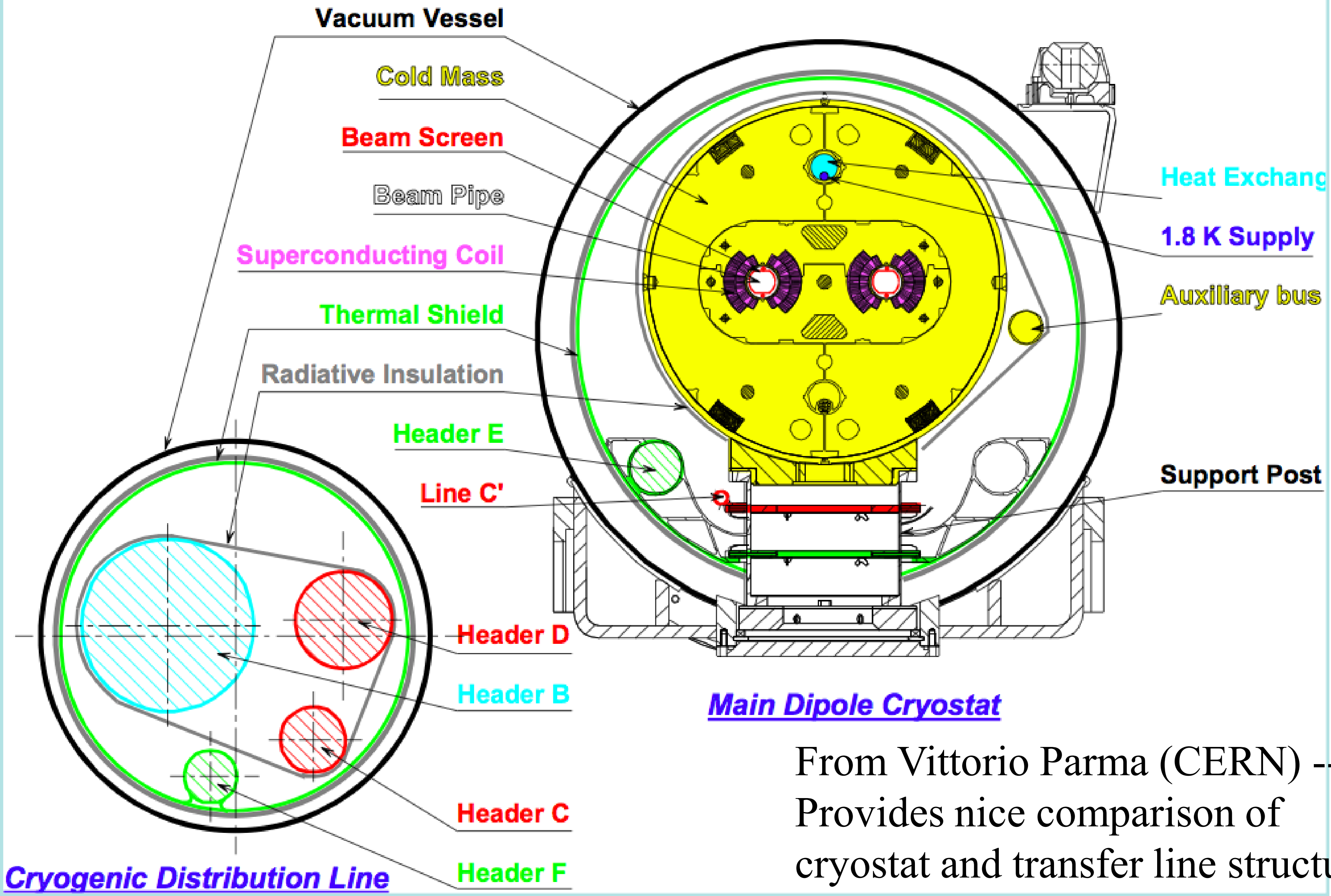
DESY TTF transfer line - 3

- Entrance to TTF building (Hall 3)

DESY TTF transfer line - 4

- Distribution box at TTF end of transfer line

Typical LHC Cross-section



Main Dipole Cryostat

Cryogenic Distribution Line

From Vittorio Parma (CERN) -- Provides nice comparison of cryostat and transfer line structures

CERN QRL installation

Reported transfer line heat loads

- Tevatron (C. Rode, et. al., in Advances in Cryogenic Engineering, Vol 27, pg. 769)
  - 80 K to 4.5 K ~33 mW/m (48 mm OD)
  - 300 K to 80 K ~0.5 W/m
- HERA (M. Clausen, et. al., in Advances in Cryogenic Engineering, Vol 37A, pg. 653)
  - 40-80 K to 4.5 K ~130 mW/m (60 mm supply + 140 mm return), consistent with about 210 mW/m^2 of inner line (compare to 50 mW/m^2 for heat load through MLI)
  - 300 K to 40-80K ~1.0 W/m
- LEP flexible transfer lines (H. Blessing, et. al., in Advances in Cryogenic Engineering, Vol 35B, pg. 909.
  - 30 mW/m on inner (4.5 K) line (13 mm OD)

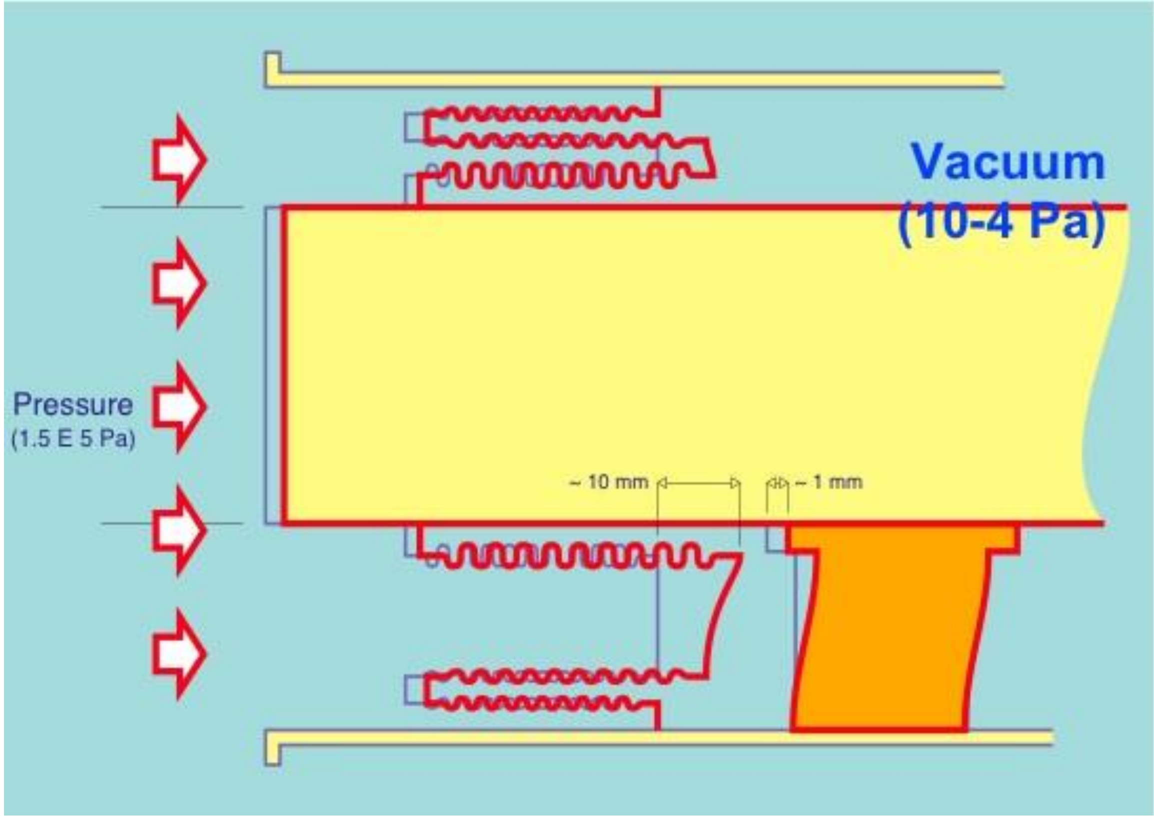
Some reported transfer line costs

- CERN and Fermilab estimate from recent experience
  - ~$8000/meter for large (600 mm OD vac jacket) transfer line (installed cost)
- Fermilab estimate
  - ~$1000/meter for typical, small 4.5 K transfer line (installed cost)

Vacuum barriers

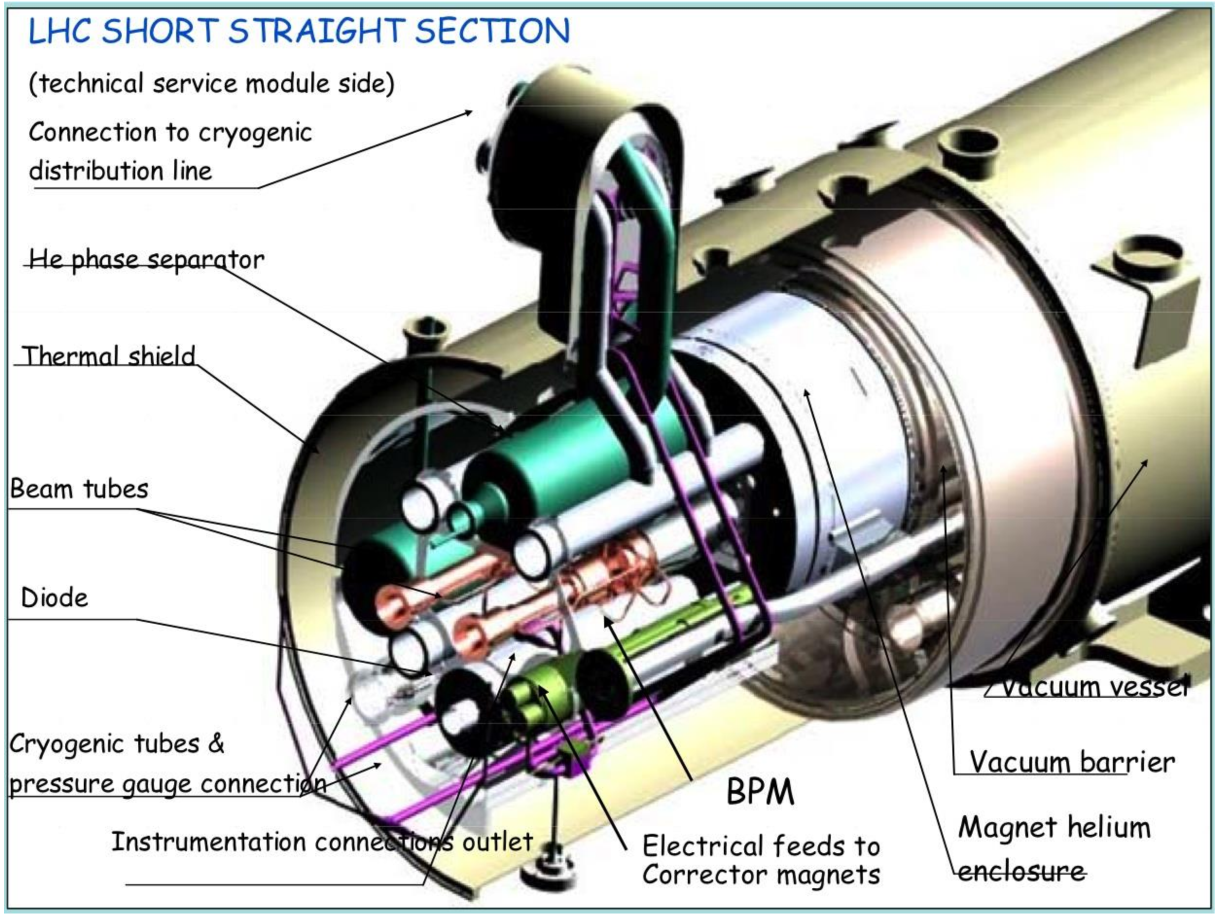
- Separate insulating vacuum into manageable sections
    - Leak checking and trouble-shooting
    - Reduce extent of accidental loss of vacuum
    - Regions for vacuum instrumentation

Vacuum barrier schematic

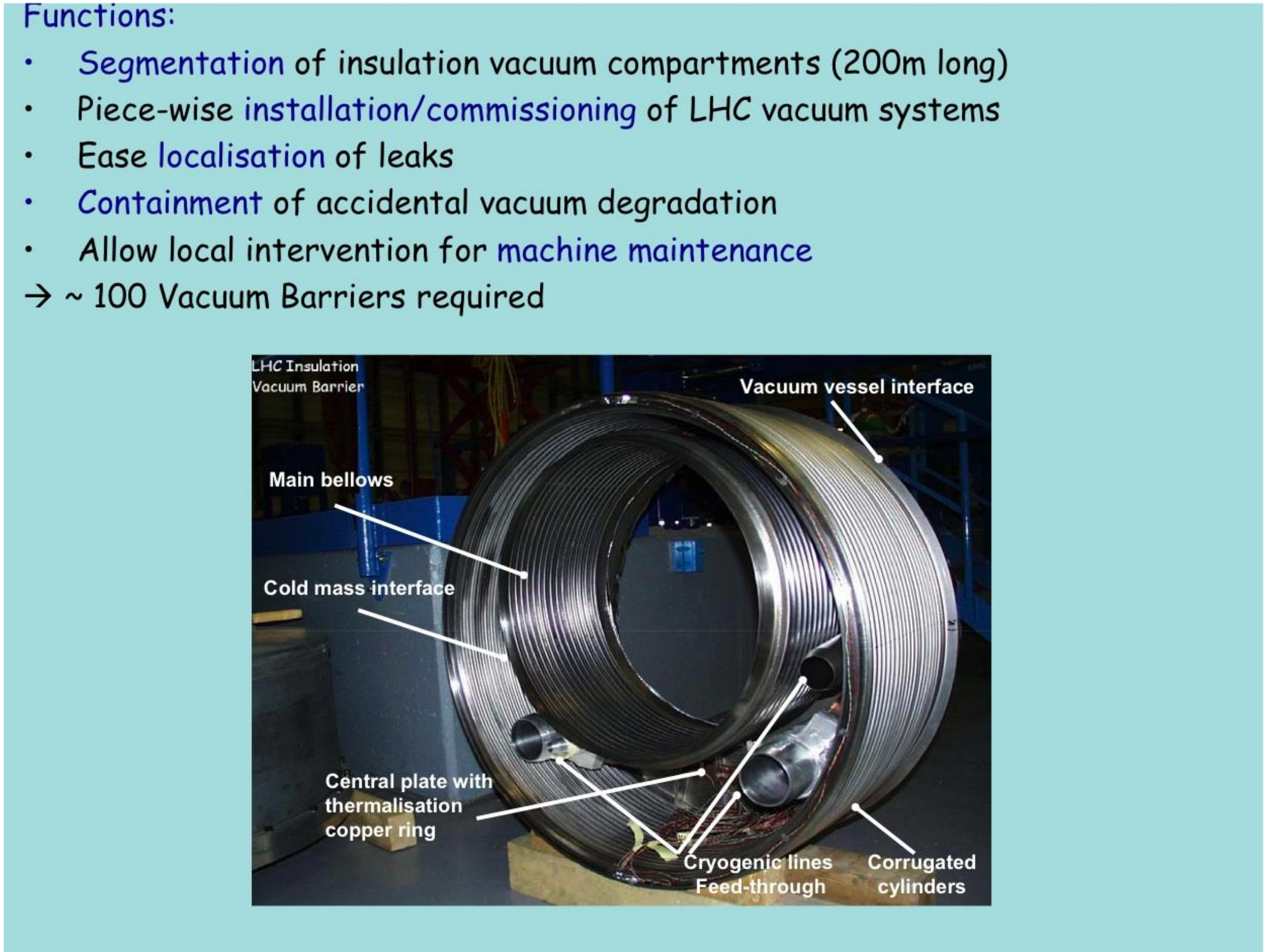


CERN's Short Straight Section

Vittorio Parma -- CERN



Vacuum barrier in SSS



Functions:

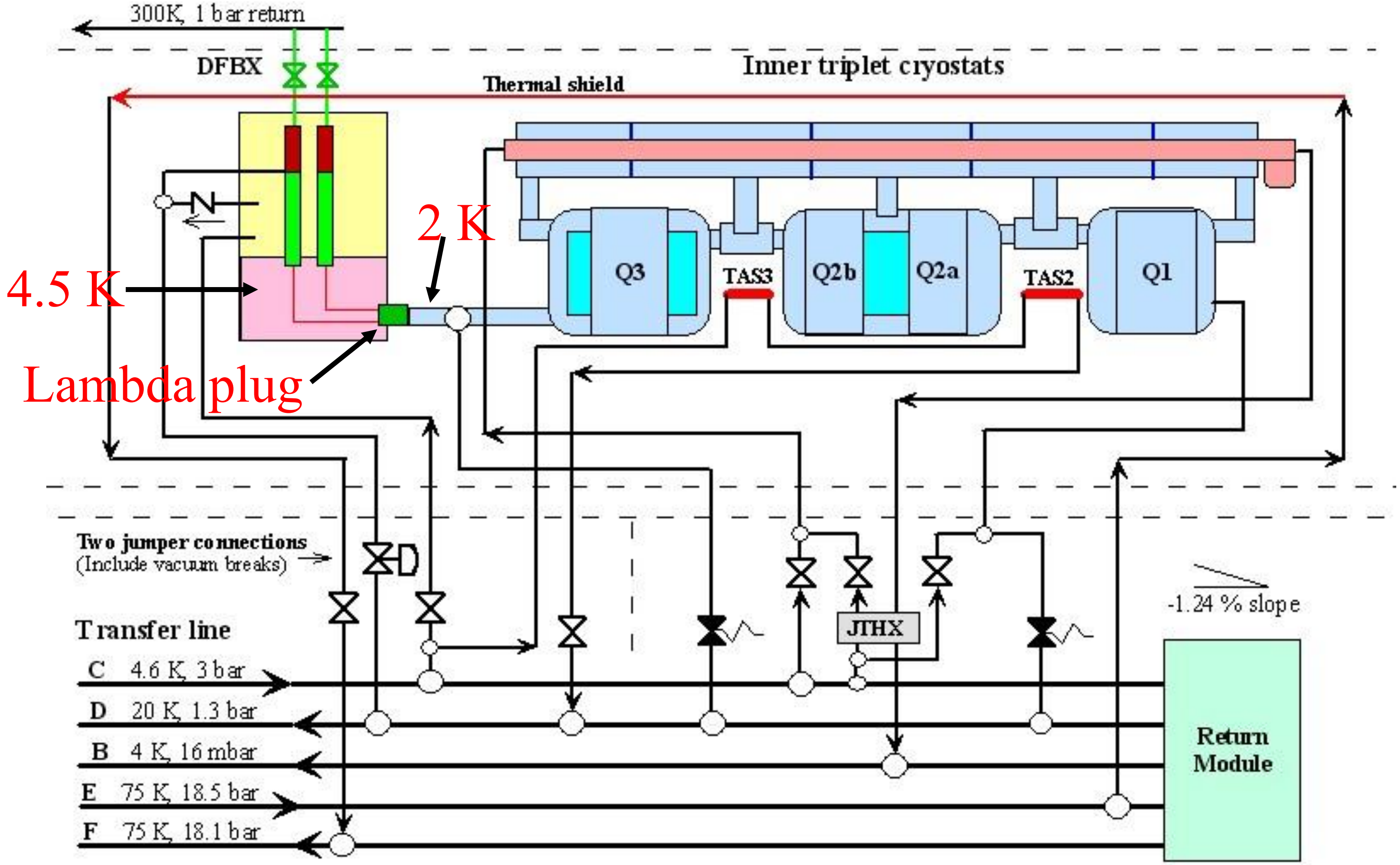
- Segmentation of insulation vacuum compartments (200m long)
- Piece-wise installation/commissioning of LHC vacuum systems
- Ease localisation of leaks
- Containment of accidental vacuum degradation
- Allow local intervention for machine maintenance

→ ~ 100 Vacuum Barriers required

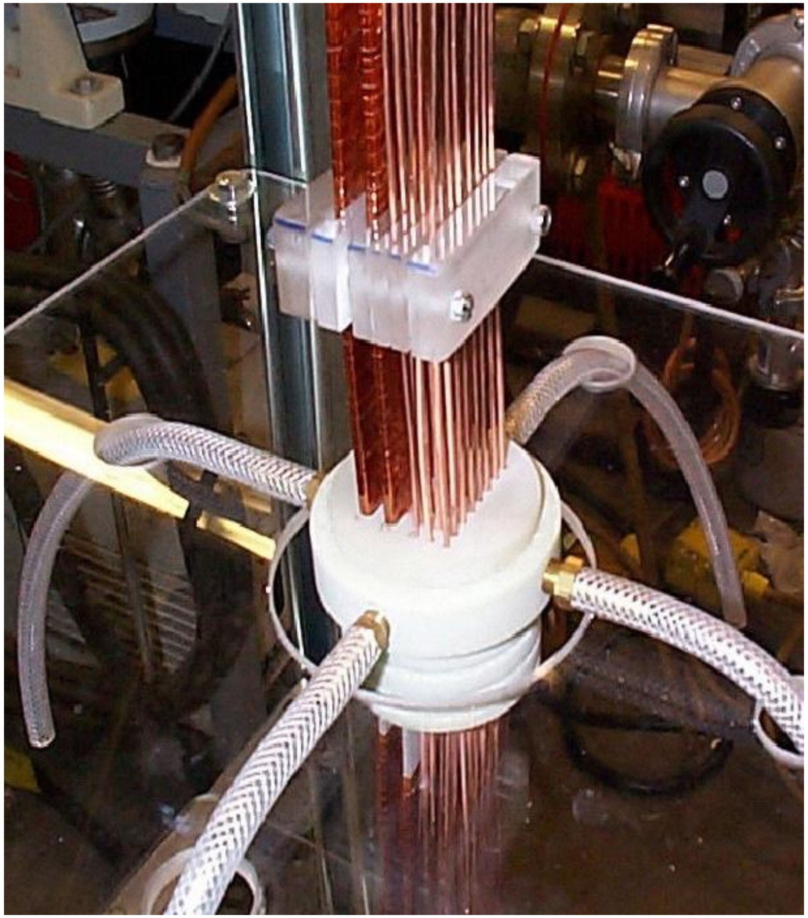
Lambda plugs

- An end box for pressurized superfluid will need to pass instrumentation and power into the superfluid region
  - Feedthrough via vacuum space, directly to SF volume
    - Risk of helium to vacuum leak
  - ➡ Feedthrough via 4.5 K helium space to superfluid space
    - Must limit heat transfer from 4.5 K to 2 K
    - This is sometimes called a “lambda plug”
    - Typically required for current leads
    - LHC has many
- Failure results in a heat load to 2 K level

Simplified LHC magnet cooling scheme

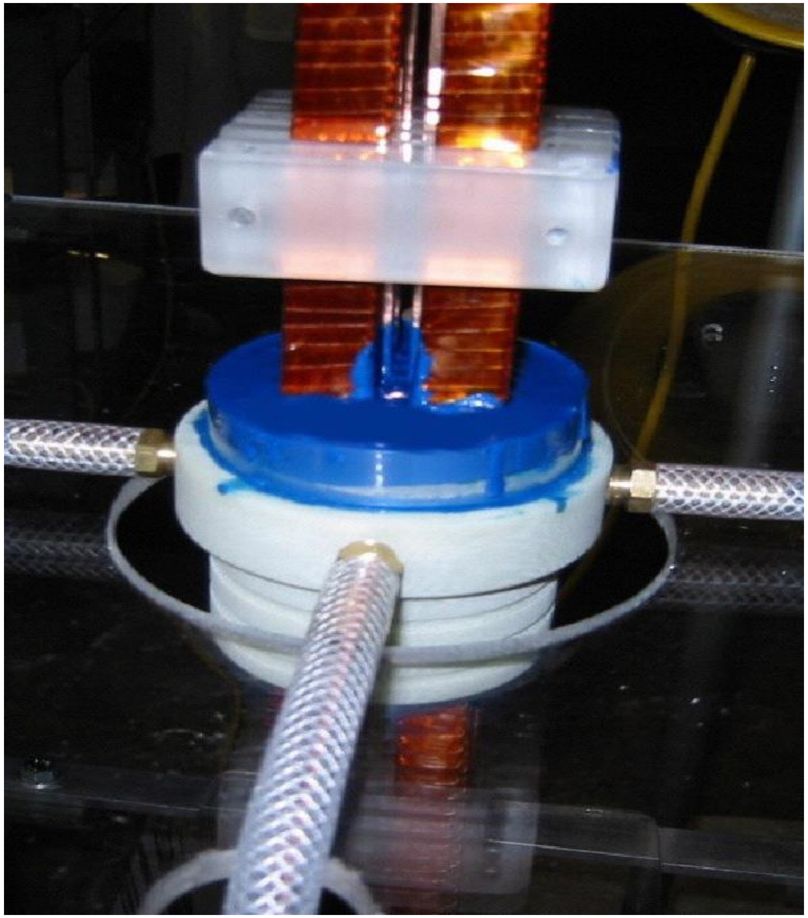


Lambda plug fabrication (LBNL)- 1



- Superconducting cable potted in an insulating block of G10-CR
  - Plane of reinforcement parallel to faces
  - Four 8 kA cables and 24 200-600 A cables
- Plug design and procedures developed at Berkeley Lab

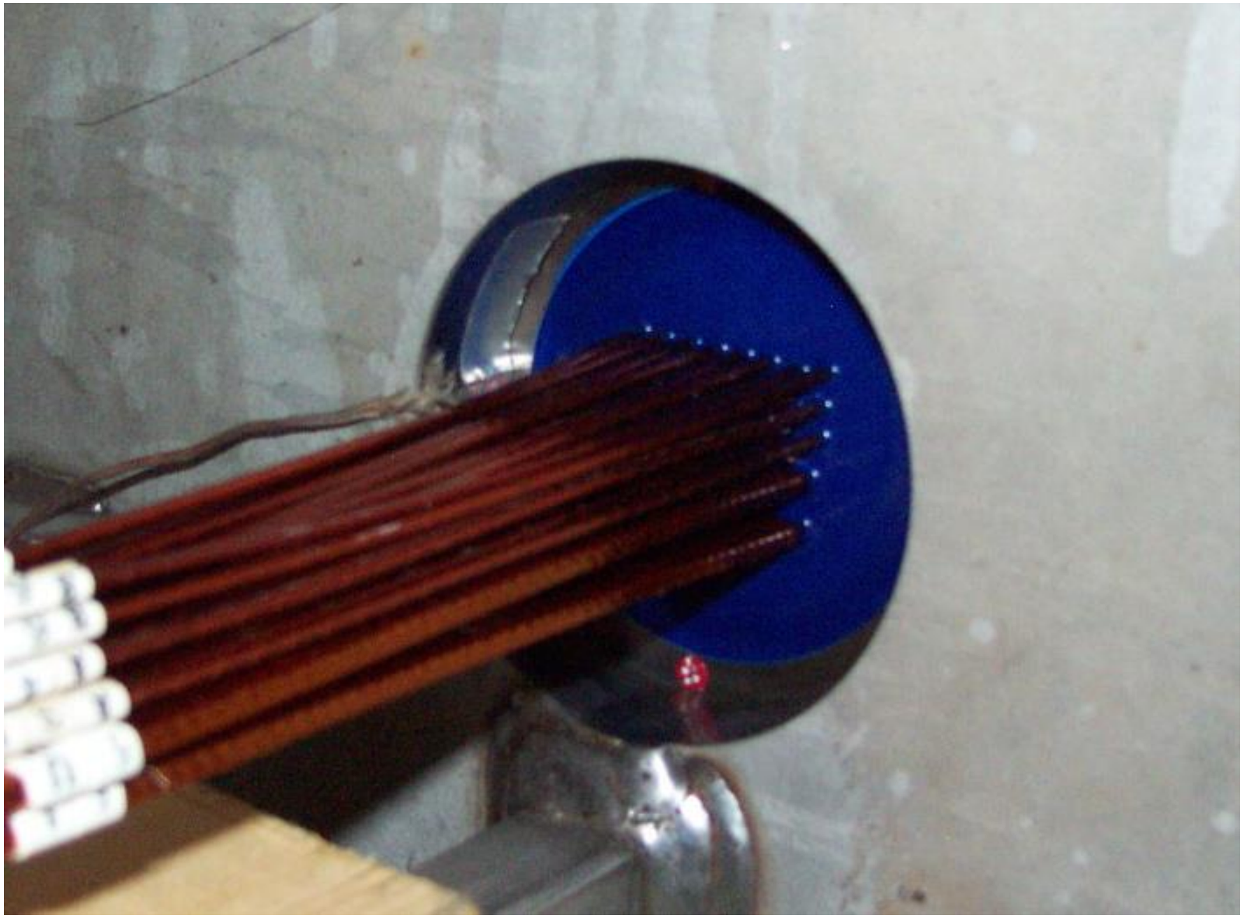
Lambda plug fabrication - 2



- Encapsulated in Stycast 2850MT (blue) epoxy using hardener 24LV
- Application via injection in a vacuum chamber

Lambda plug installed -1

View of lambda plug from 4.5 K helium vessel



Lambda plug installed -2

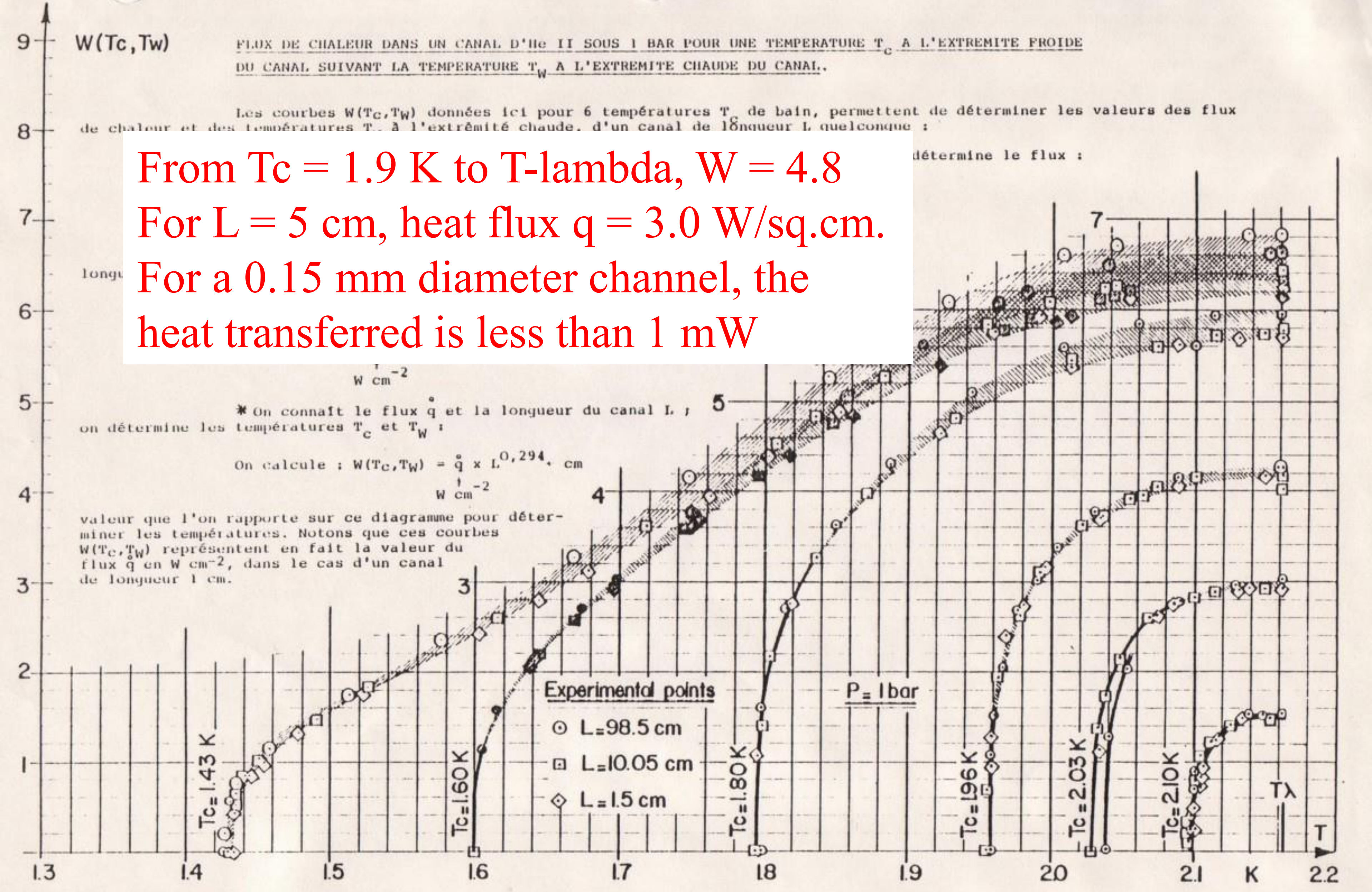
View of lambda plug installation from vacuum space

Lambda plug installed -3

View of support flange and 1.9 K pipe from insulating vacuum space

Allowable leak rate -- example

- For these lambda plugs, an allowable leak rate was determined based on allowable heat transport through a crack
  - 0.15 mm channel results in less than 1 mW heat from 4.5 K side to 1.9 K side
- Channel size converted to an equivalent room temperature air flow
- Air leak rate measured as a QC check



FLUX DE CHALEUR DANS UN CANAL D'He II SOUS 1 BAR POUR UNE TEMPERATURE T_c A L'EXTREMITE FROIDE DU CANAL SUIVANT LA TEMPERATURE T_W A L'EXTREMITE CHAUDE DU CANAL.

Les courbes $W(T_c,T_W)$ données ici pour 6 températures T_c de bain, permettent de déterminer les valeurs des flux de chaleur et des températures T_W à l'extrémité chaude, d'un canal de longueur L quelconque :

longu

détermine le flux :

W cm^{-2}

* On connaît le flux $\dot{q}$ et la longueur du canal L ; on détermine les températures T_c et T_W :

On calcule : $W(T_c,T_W) = \underset{W\,cm^{-2}}{\dot{q}} \times L^{0,294}$. cm

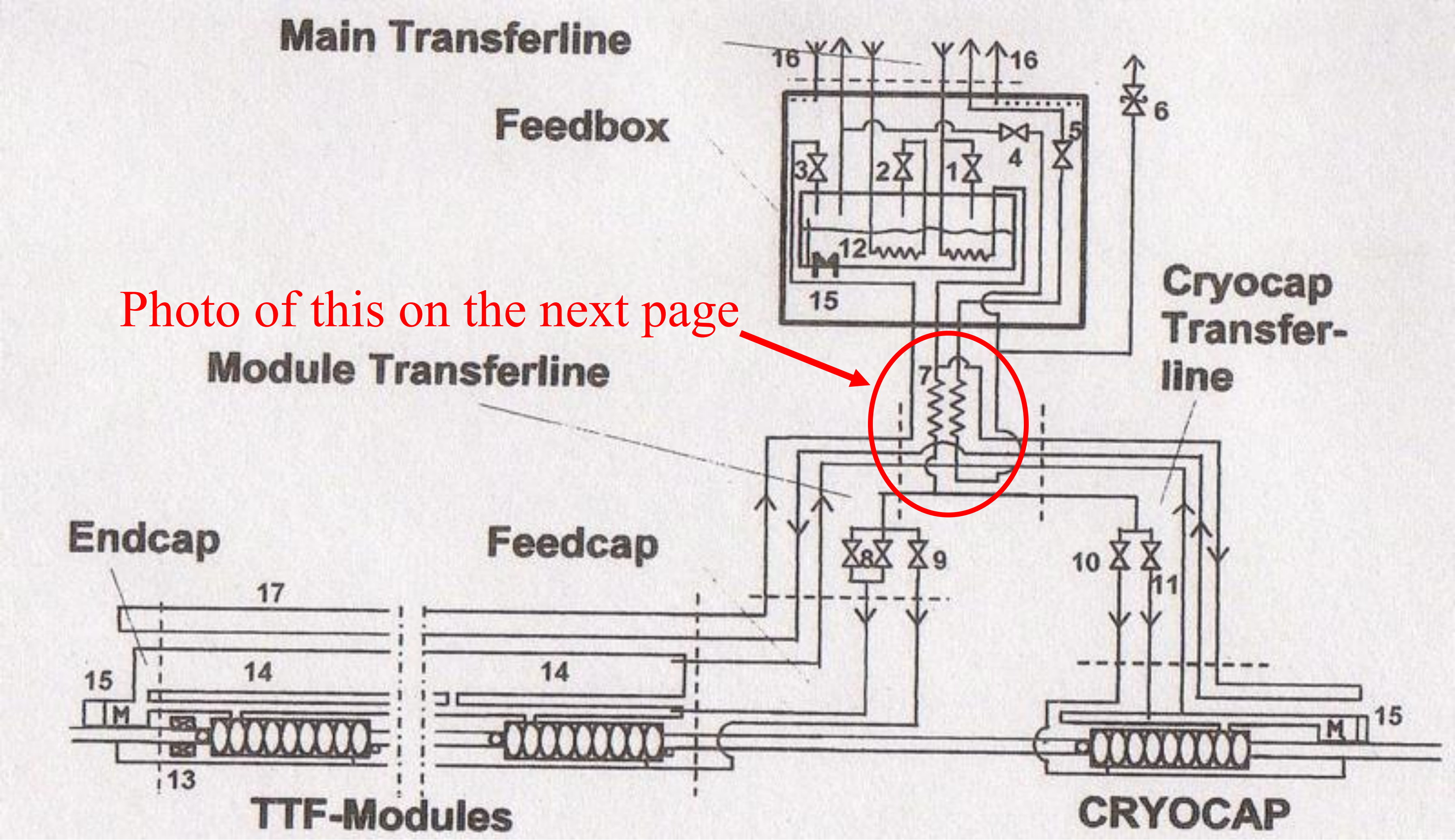
valeur que l'on rapporte sur ce diagramme pour déterminer les températures. Notons que ces courbes $W(T_c,T_W)$ représentent en fait la valeur du flux $\dot{q}$ en W cm^{-2}, dans le cas d'un canal de longueur 1 cm.

From Tc = 1.9 K to T-lambda, W = 4.8
For L = 5 cm, heat flux q = 3.0 W/sq.cm.
For a 0.15 mm diameter channel, the heat transferred is less than 1 mW

TTF feed box

- TESLA Test Facility (TTF) at DESY is a small SRF system, so feed box is like an SRF test feed box
  - Receives 4.5 K He
  - Internal heat exchangers for 2 K generation
  - Connection to large room temperature pump
- Designed and built at Fermilab for TTF at DESY

TTF feedbox schematic



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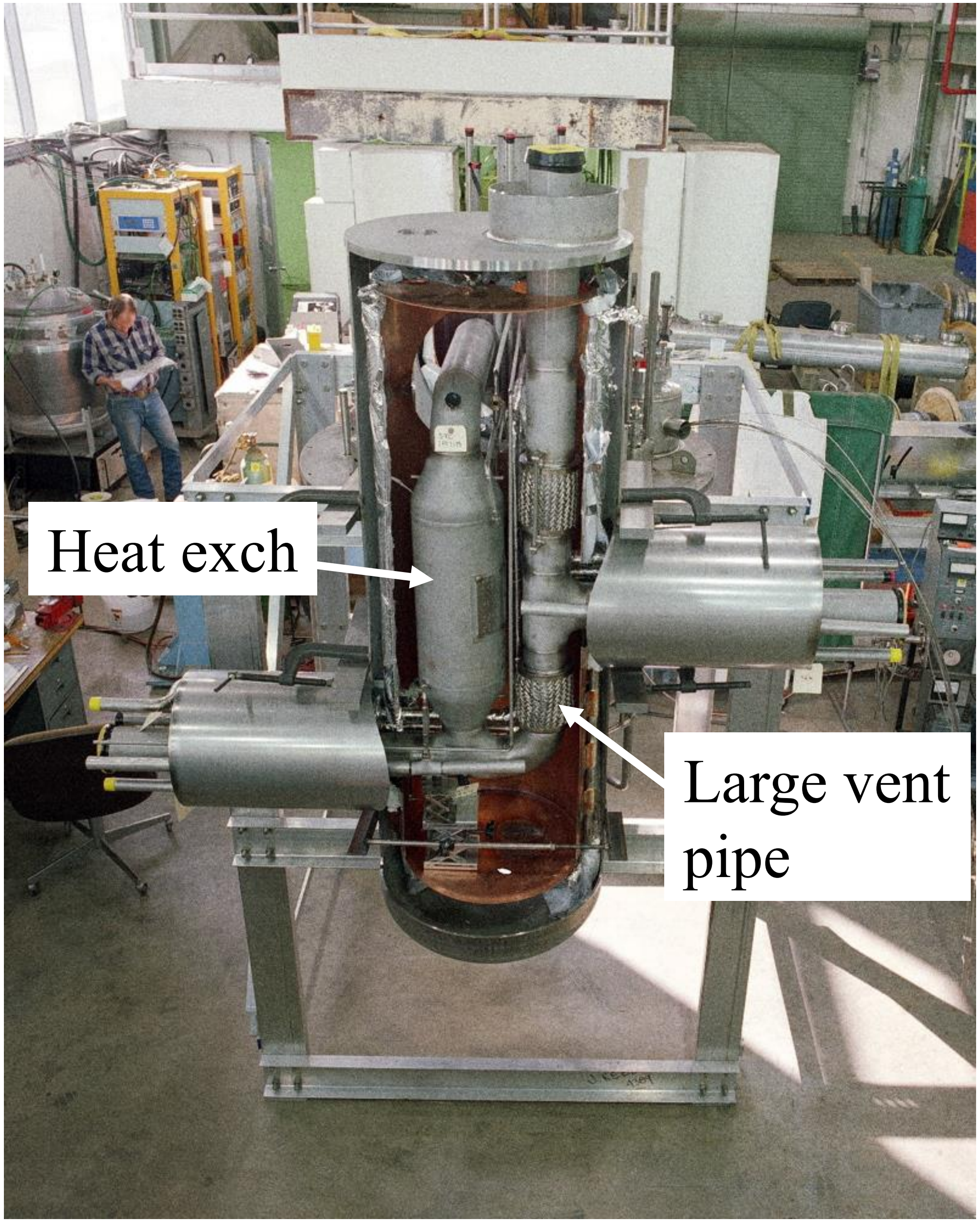
TTF feedbox internal



- 2 K end of piping
  - 4.5 K to 2 K heat exchanger
  - Large vent line
- Note short braided hose on large vent pipe for small thermal motion
- Copper thermal shield

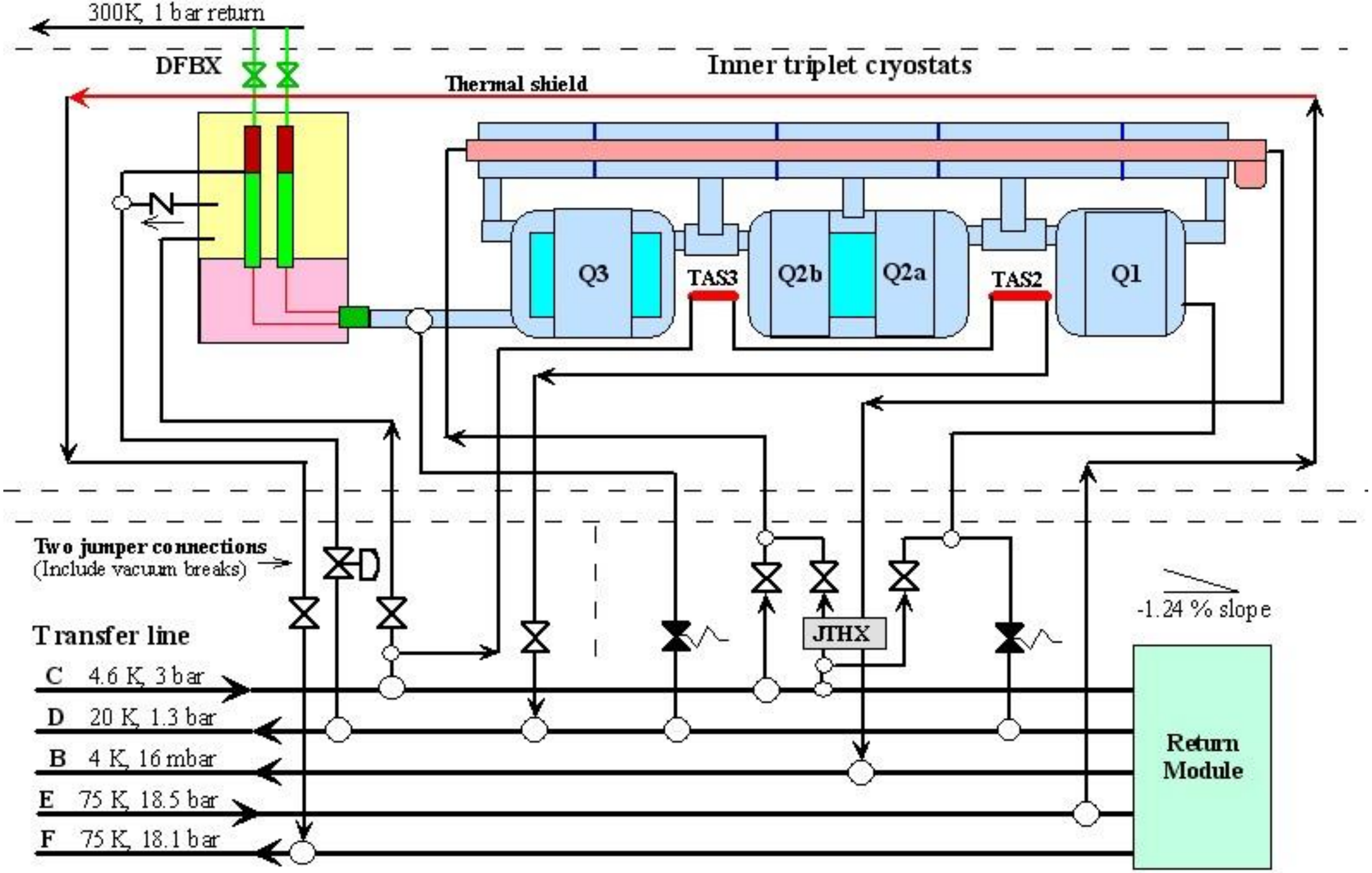
LHC test string 2 feed box (CERN)

Many current leads and ports for access to make splice joints

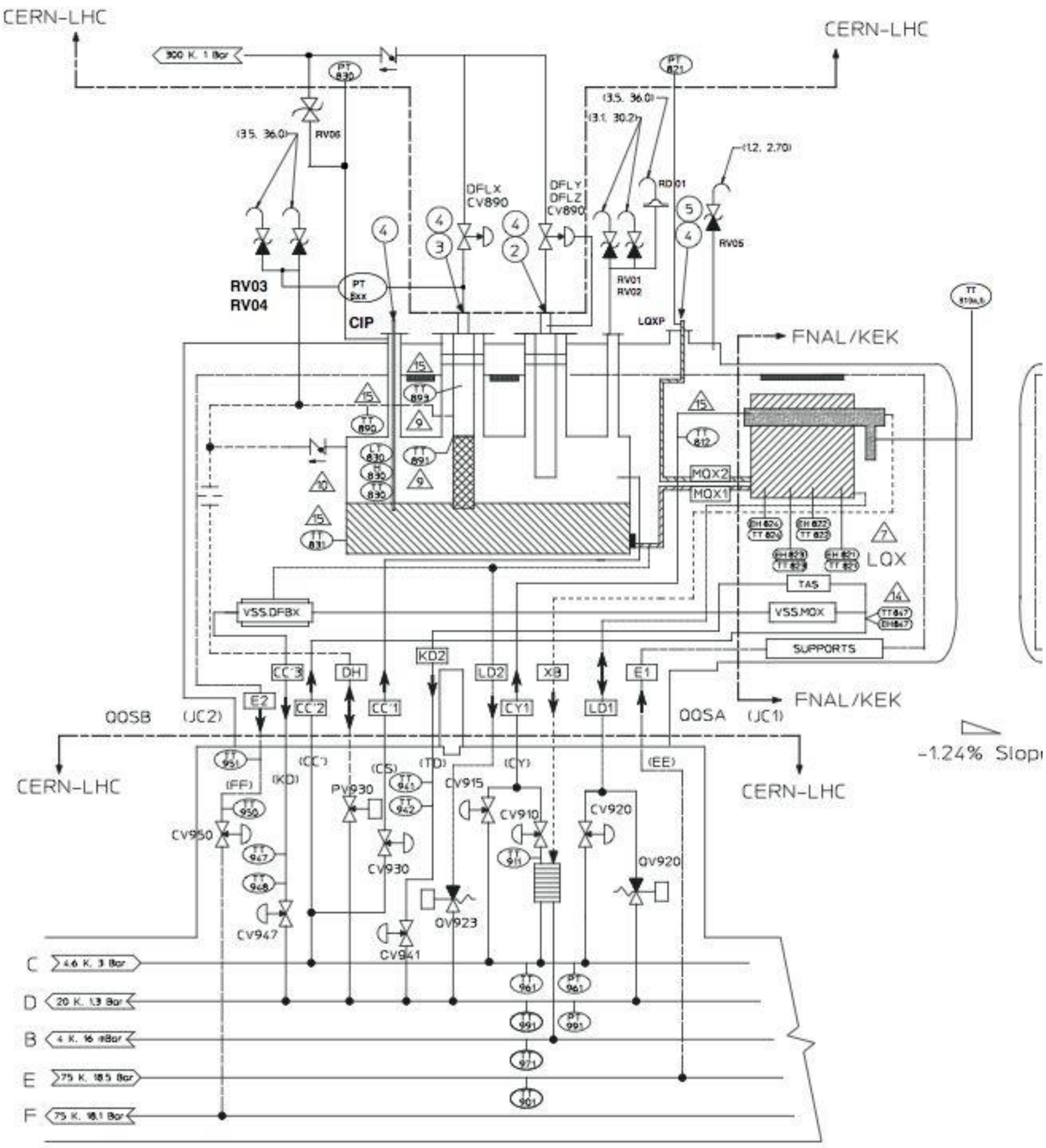
Distribution box: DFBX

- Distribution feed boxes (DFBX) for LHC at CERN
- Designed by Lawrence Berkeley National Lab with assistance from Fermilab
- Provide cryogens, electrical power, and instrumentation interface between CERN cryogenic system and US-supplied final focus quadrupoles

LHC magnet cooling scheme



IP5 Left – DFBXE

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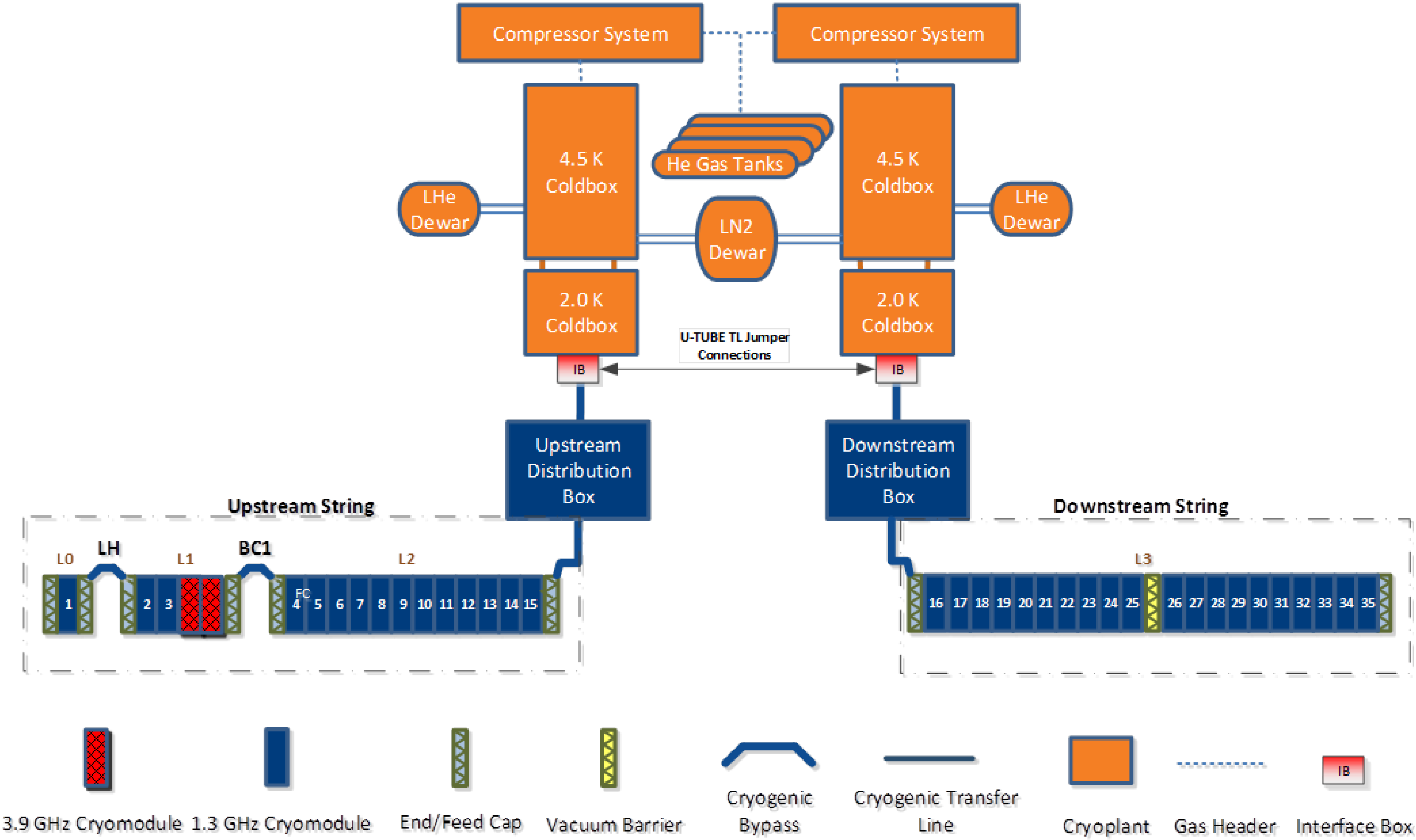
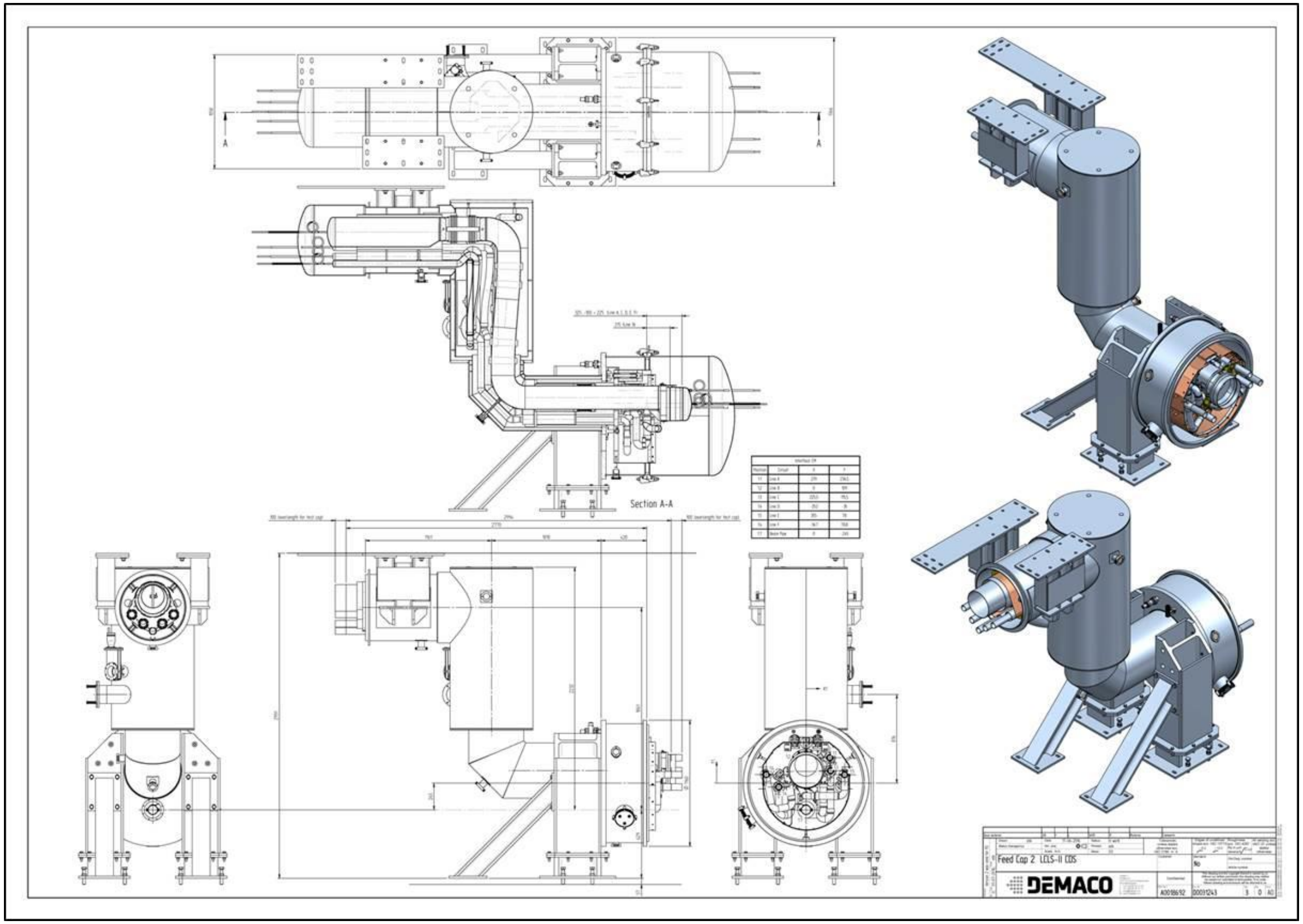
LCLS-II Cryogenic Distribution



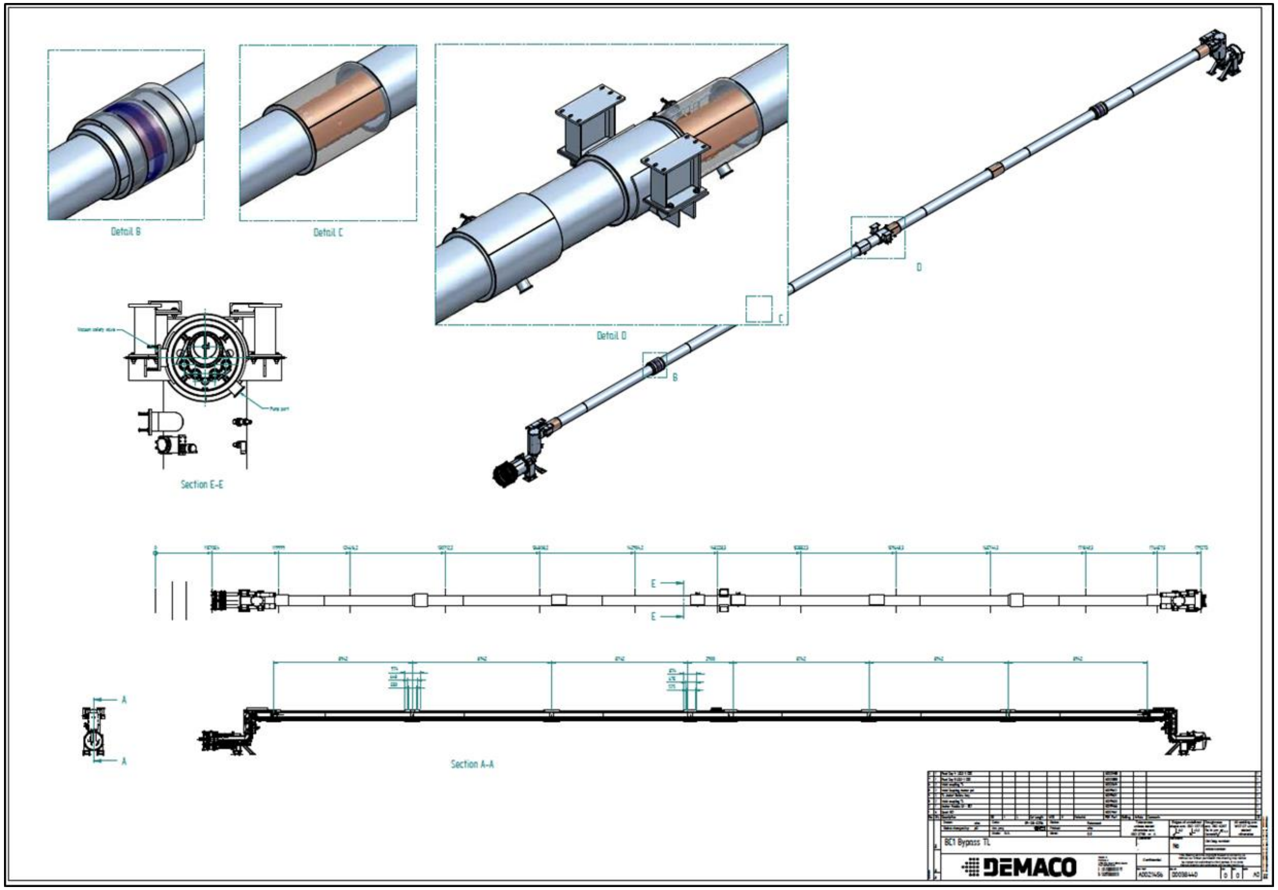
LCLS-II Feed Caps 2 and 4

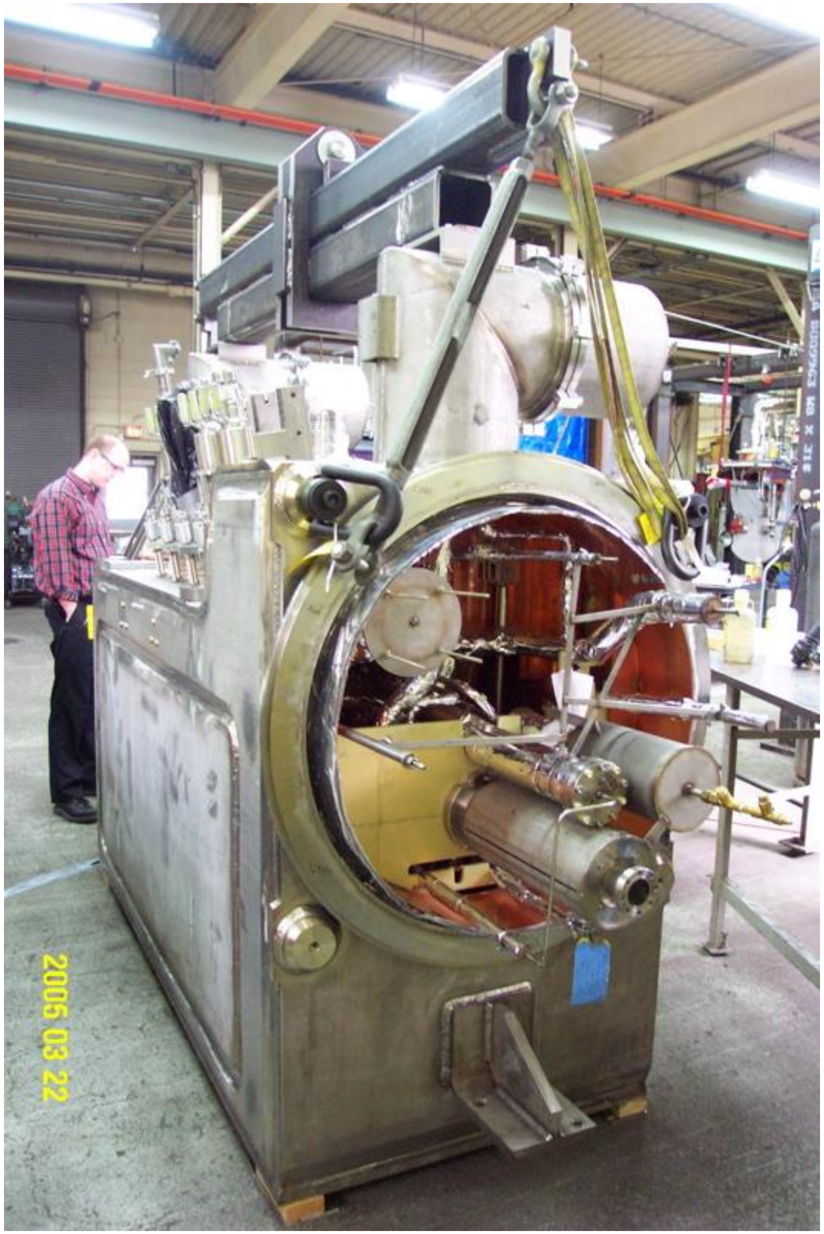
(Arkadiy Klebaner, Fermilab, and DEMACO)



LCLS-II BC1 Bypass

(Arkadiy Klebaner, Fermilab, and DEMACO)





Conclusion:

Cryogenic distribution equipment often occupies a major fraction of cryogenic engineering time for a project. It may be non-standard, integrates many different components into one cryostat, and involves sizing of valves, relief valves, pipes, pressure vessel issues, heat transfer considerations, etc., etc. Significant and interesting mechanical engineering!

References

- V. Parma, “Construction Experience of the LHC Cryostats,” presentation at ILC GDE meeting, 11 Sep 2007
- C. Rode, et. al., “Fermilab Tevatron Transfer Line,” in Advances in Cryogenic Engineering, Vol 27, pg. 769.
- M. Clausen, et. al., “Cryogenic Test and Operation of the Superconducting Magnet System in the HERA Proton Storage Ring,” in Advances in Cryogenic Engineering, Vol 37A, pg. 653.
- H. Blessing, et. al., “Very Low-Loss Liquid Helium Transfer with Long Flexible Cryogenic Lines,” in Advances in Cryogenic Engineering, Vol 35B, pg. 909.