Distribution Systems

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Summer 2021

Goals

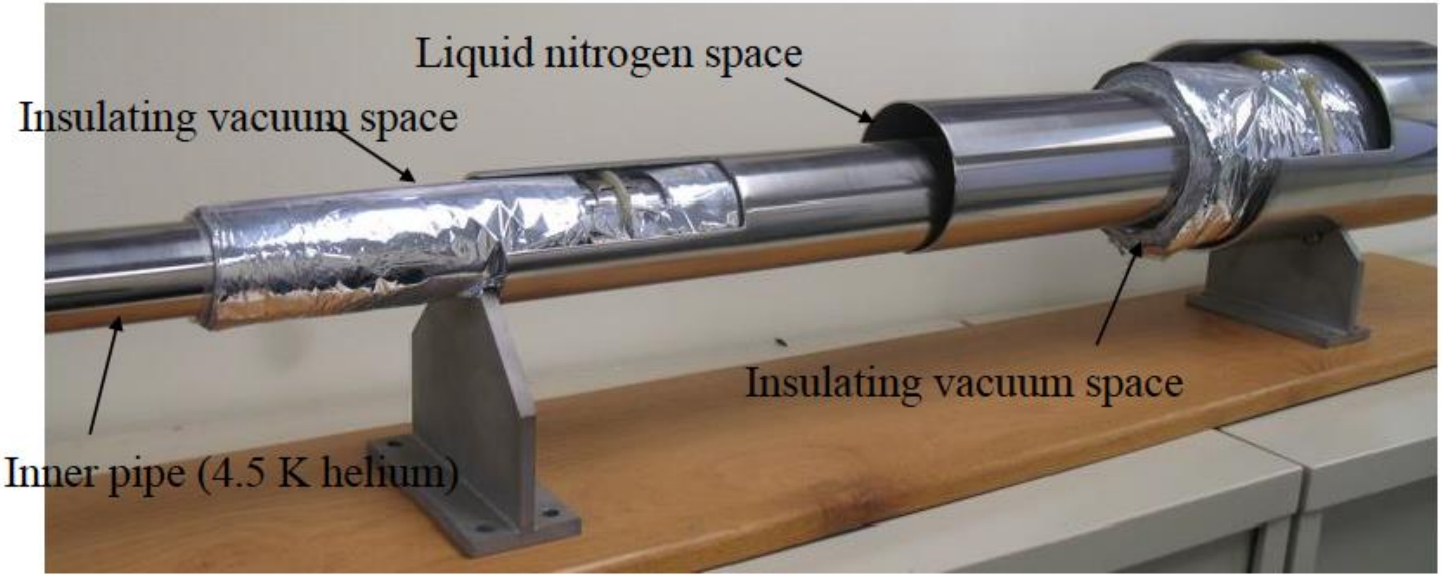
- Describe the nature, performance and design considerations of Transfer Lines, Distribution Systems and Distribution (valve) boxes in cryogenic systems
- Show examples of typical components
- Thanks to Tom Peterson (SLAC) and Jarek Fydrych (ESS) for significant contributions.

Transfer Lines

- Vital part of a cryogenic system
  - Transfers cryogenic fluids between components
  - Essentially a long cryostat
  - Can be a significant part of system cost and heat leak
  - Can be acquired commercially or custom built
- Key design issues
  - Thermal contraction (significant due to long lengths)
  - Heat Leak (use of active thermal shields)
  - Forces generated by fluid pressure, thermal contraction must be managed so as to not impact alignment of components
  - Vacuum integrity (pump outs, relief valves and vacuum barriers)

Transfer Line Example
Fermilab Tevatron
Note that the cooling pipes are concentric

Fermilab's 4.5 K transfer line



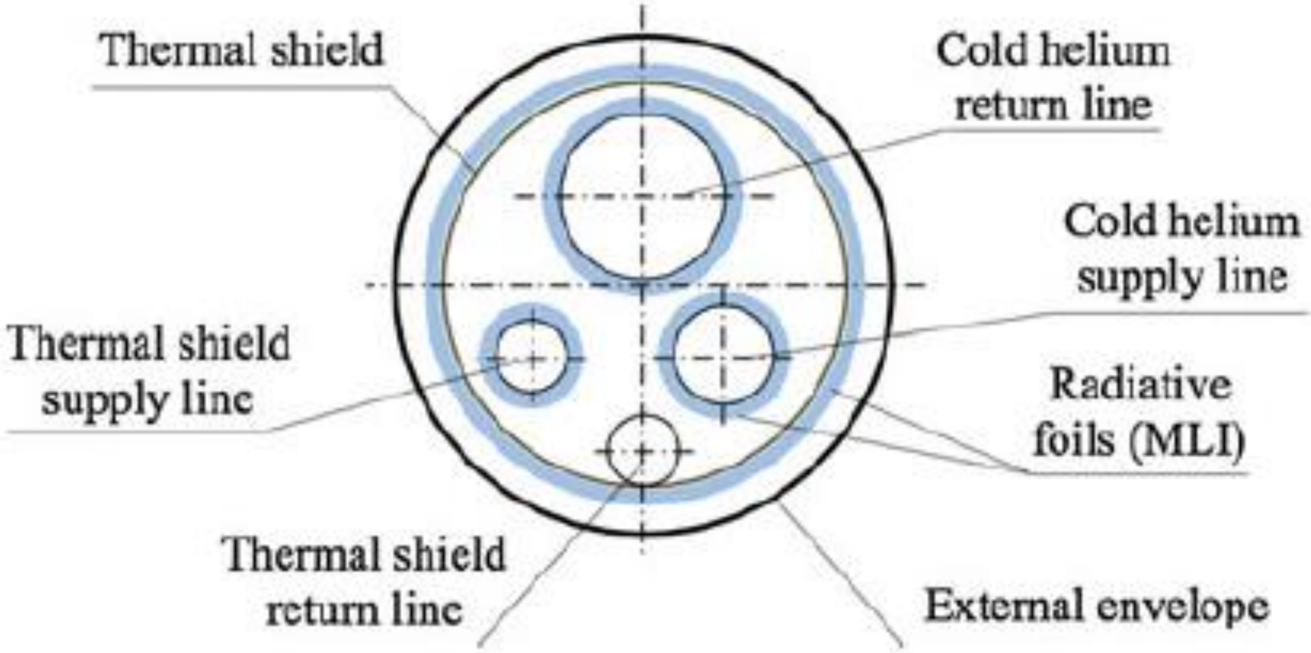
- Supplied 4.5 K, supercritical (3 bar) helium over 6 km to "satellite" refrigerators
- Also provided LN2

Transfer Line Example
Fermilab Tevatron

Fermilab's 4.5 K transfer line

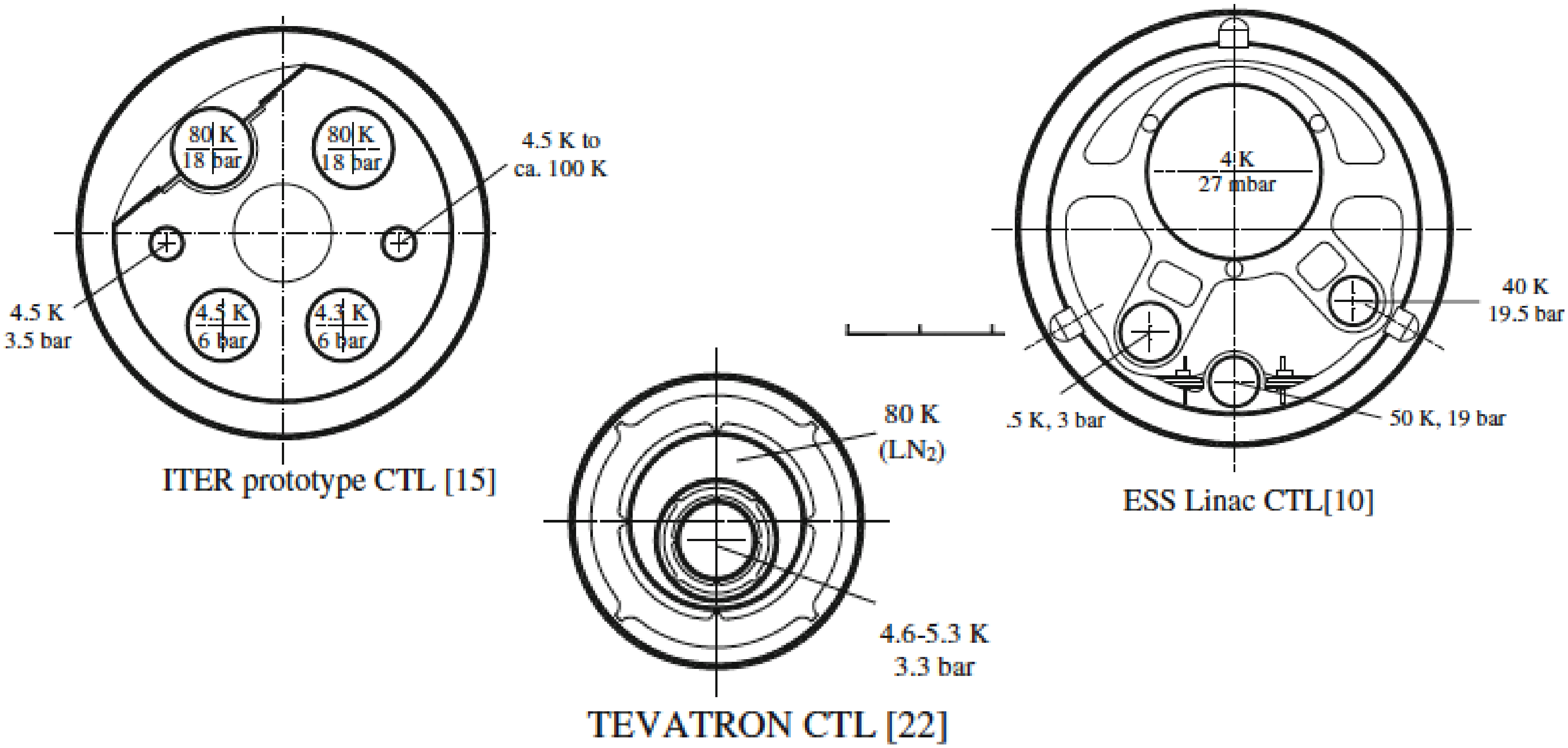
- Outside on top of the accelerator enclosure, a full 6 km circumference ring
- Here a bypass around a building

Most Transfer Lines today have parallel rather than concentric piping arrangements



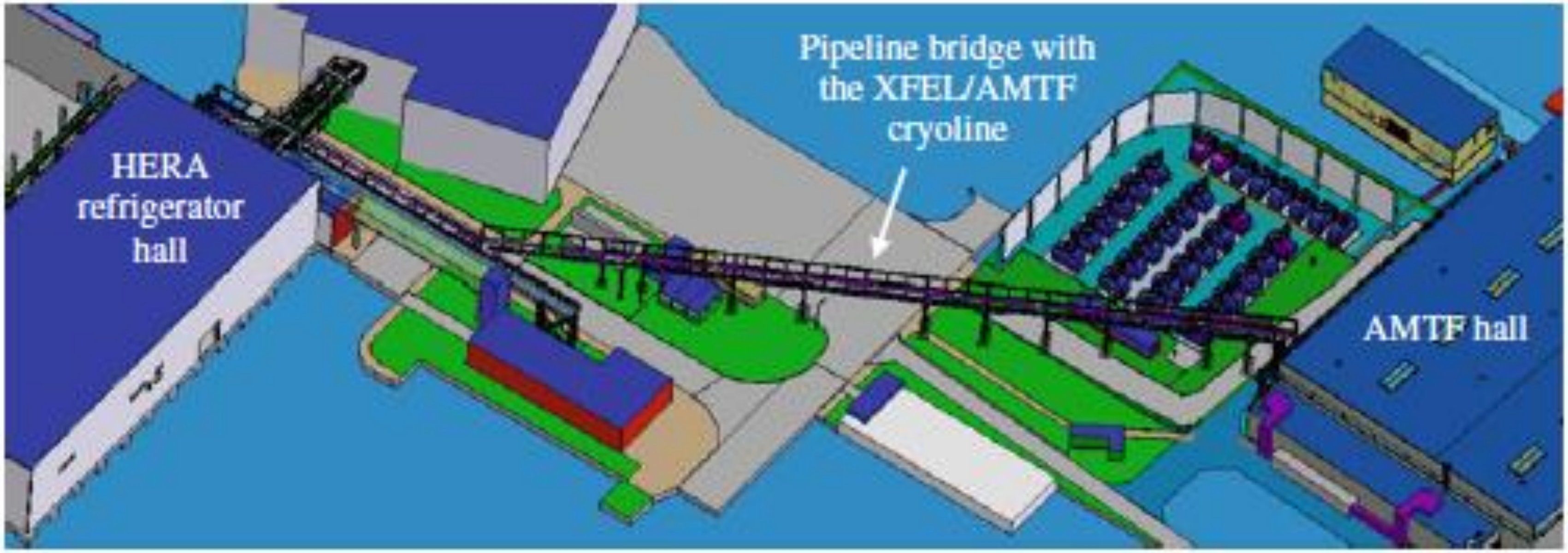
From J. Frydrych
"Transfer Lines" in *Cryostat Design*

Examples of Transfer Line Cross sections



From J. Frydrych ”Transfer Lines” in *Cryostat Design*

DESY XFEL/ AMTF Transfer Line



From J. Frydrych ”Transfer Lines” in *Cryostat Design*

Designed and built by WUST and KrioSystem
They team also provided the bulk of the ESS distribution system

DESY XFEL/ AMTF Transfer Line

Fig. 9.25 Straight module assembled (*courtesy* Kriosystem Ltd.)

From J. Frydrych ”Transfer Lines” in *Cryostat Design*

DESY XFEL/ AMTF Transfer Line

Fig. 9.29 The XFEL/AMTF cryogenic transfer line installed on the pipe bridge (*courtesy* Kriosystem Ltd.)

From J. Frydrych ”Transfer Lines” in *Cryostat Design*

ESS Transfer Line between ACCP & start of Cryogenic Distribution System

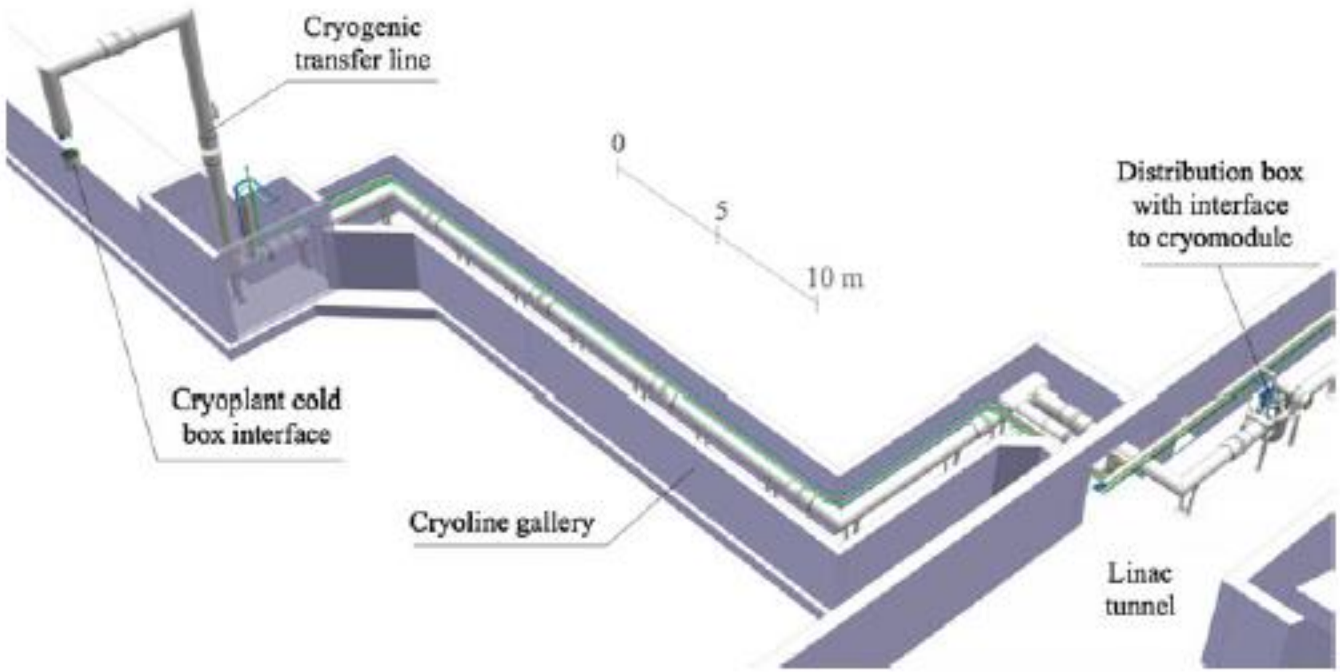


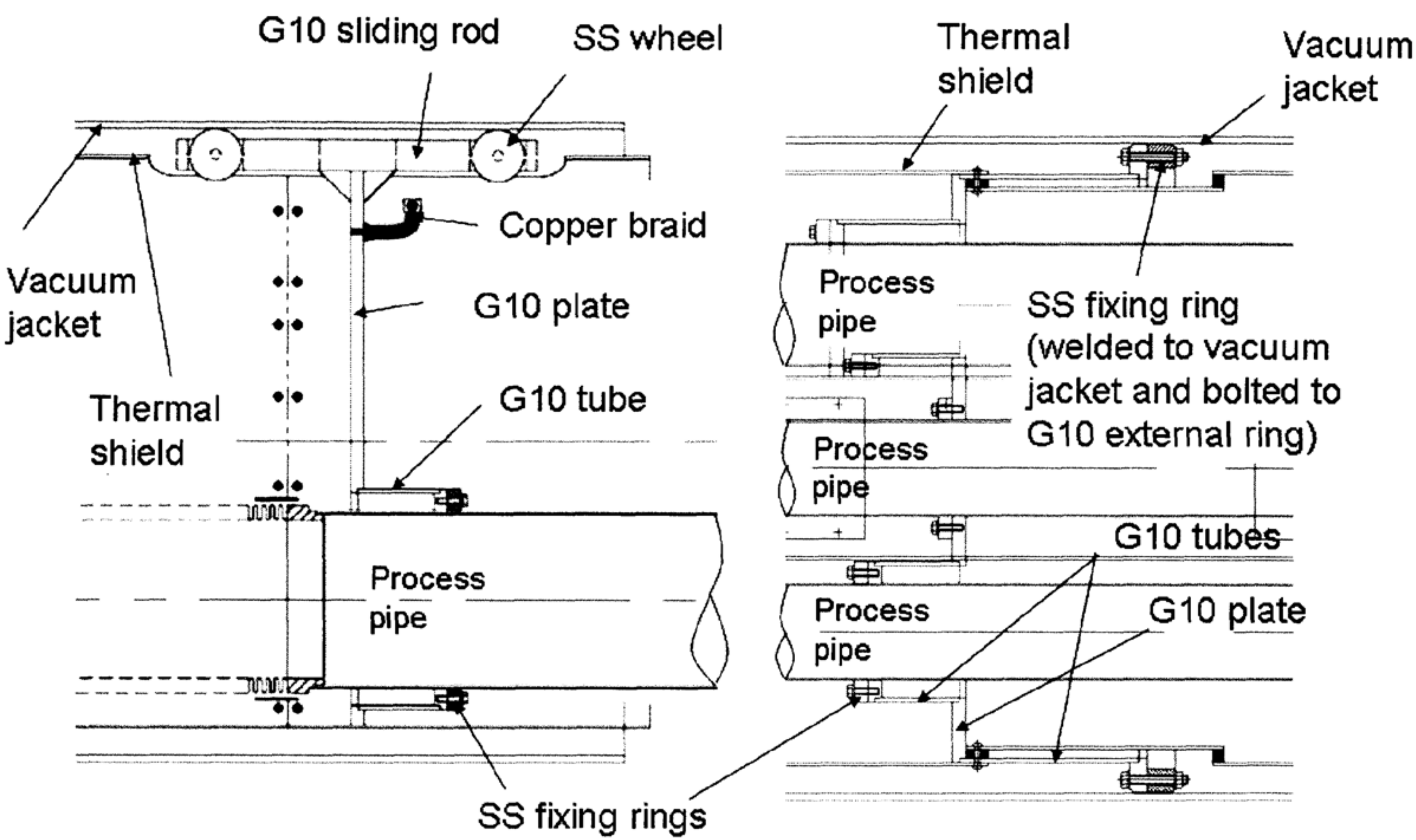
Fig. 9.4 Schematic view of the ESS linac cryogenic transfer line

From J. Frydrych ”Transfer Lines” in *Cryostat Design*

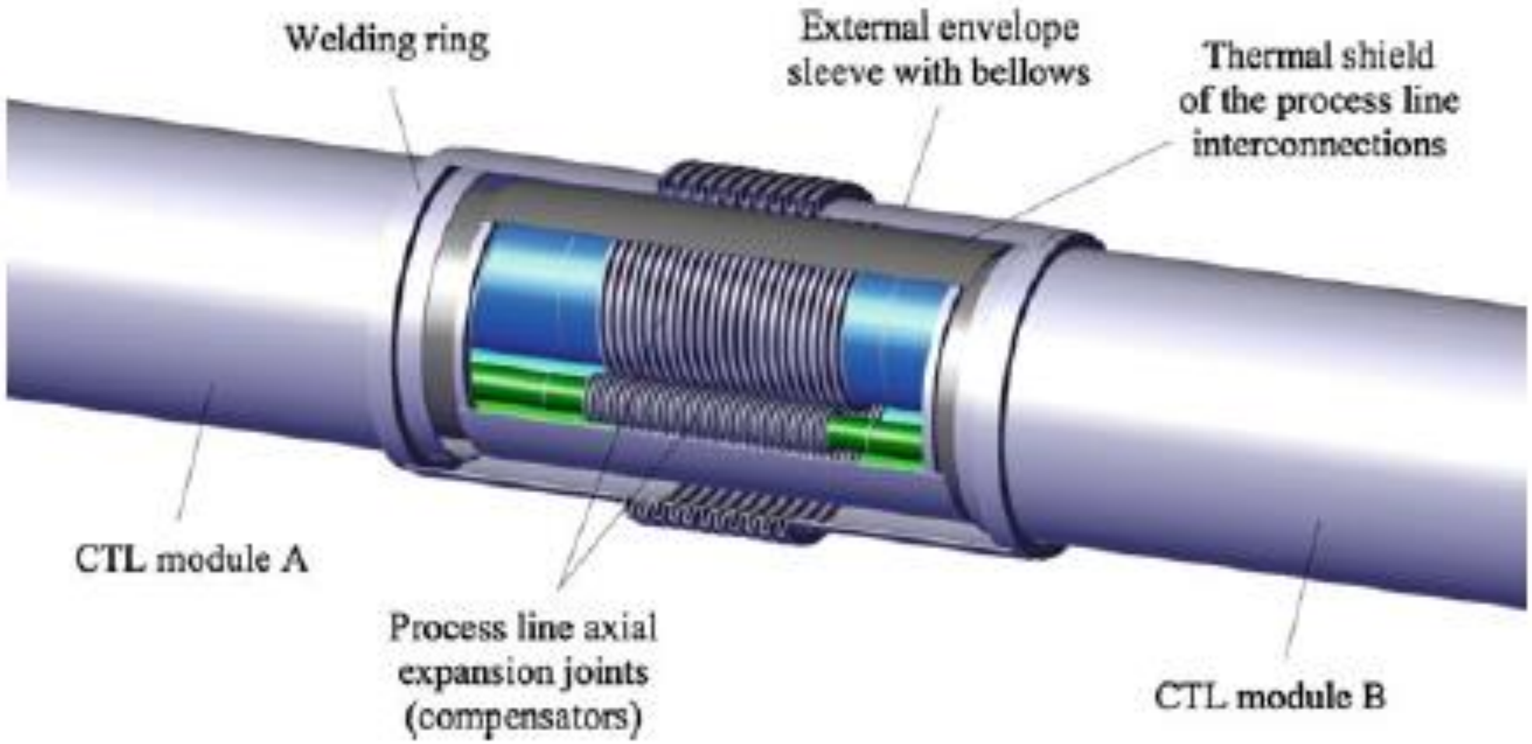
Transfer Lines

- Methods to address thermal contraction
  - Have a combination of fixed and sliding supports on the interior pipes separated by bellows.
  - Use bends to allow interior pipes to contract
  - Use Invar pipes to reduce amount of thermal contraction (CERN/LHC)

“The Local Helium Compound Transfer lines For The Large Hadron Collider Cryogenic System”
C. Parente et al. Adv. Cryo Engr. Vol 51 (2006)



Typical Interconnection Between Transfer Line Segments



From J. Frydrych ”Transfer Lines” in *Cryostat Design*

Vacuum Barriers

- Common in transfer lines and distribution systems.
- Divides isulation vacuum space into separate sections
- Must allow internal pipes to pass through
- Allows
  - Leak checking and trouble shooting
  - Reduces impact of vacuum leaks and sudden vacuum failures
  - May allow for separate warm up and cool down of sytem components (ESS)

Example of a Vacuum Barrier

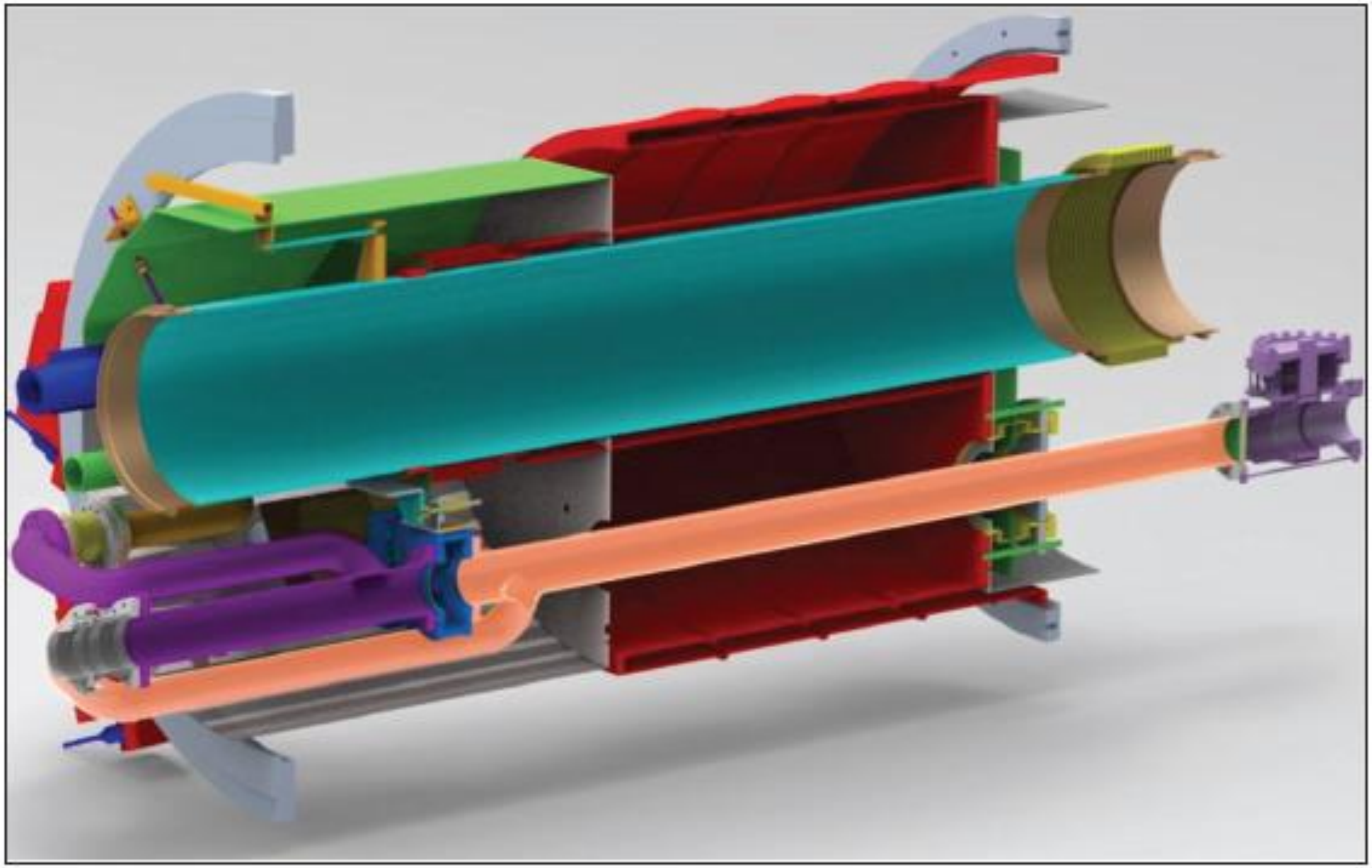


Figure 1: Example of a vacuum barrier design. Note the long thin paths between room temperature and the cryogenic pipes. Image courtesy T.J. Peterson, SLAC.

Some Reported Heat Loads for Transfer Lines

- 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)

Example Transfer Line Costs

- CERN and Fermilab estimates from experience (~2014)
  - ~$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)

Note that these numbers are for simple transfer lines, once complicated distribution boxes are included the costs grow significantly

Complicated Transfer Lines Become Distribution Systems

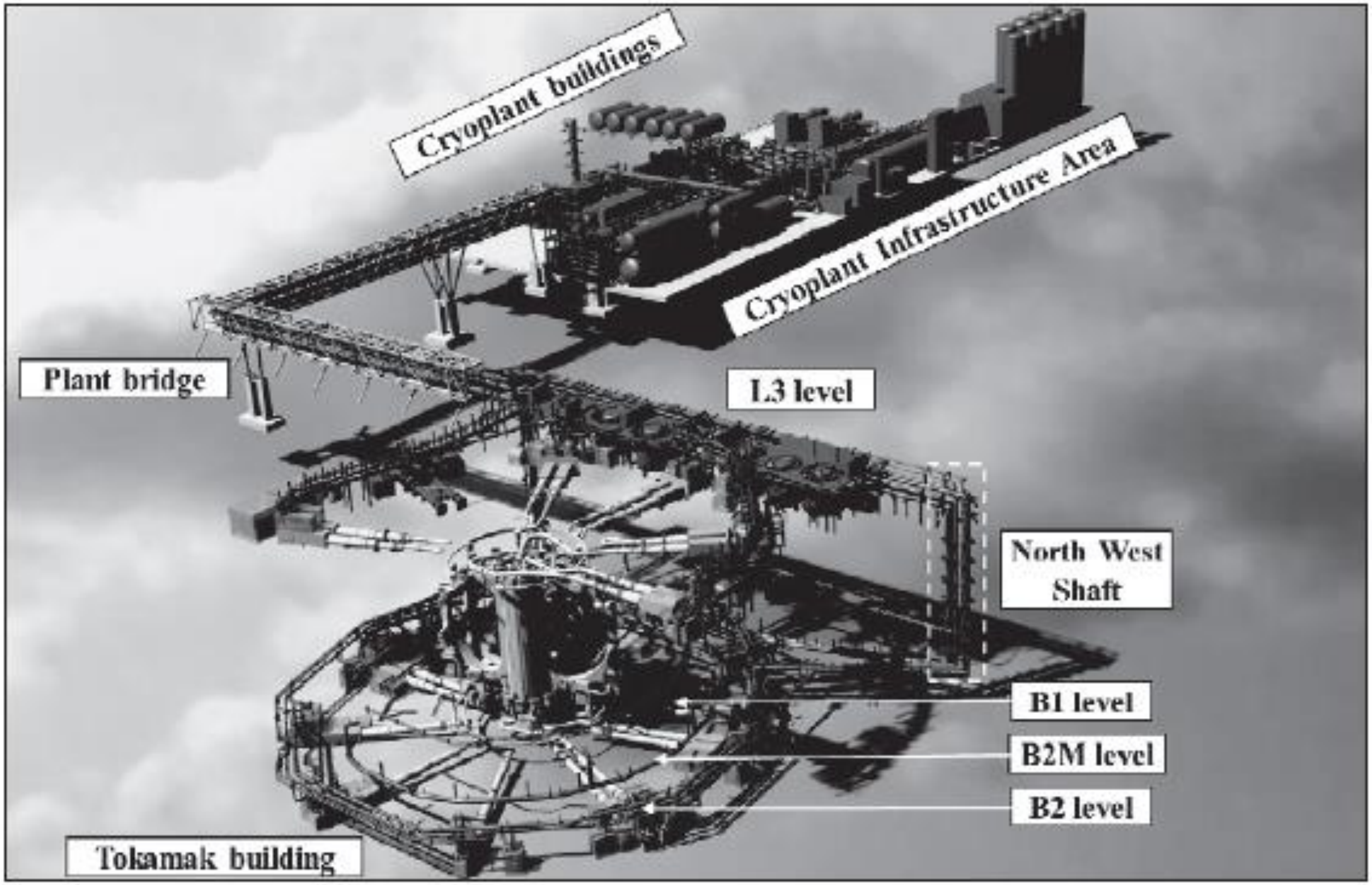
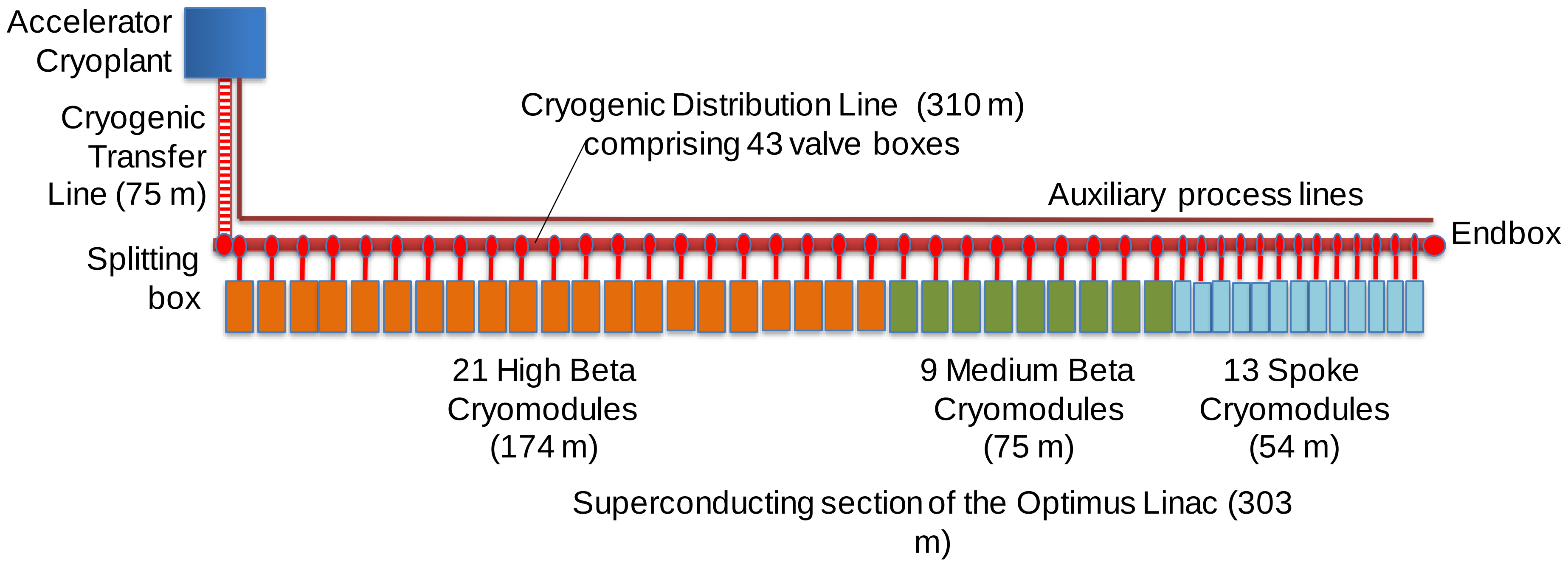


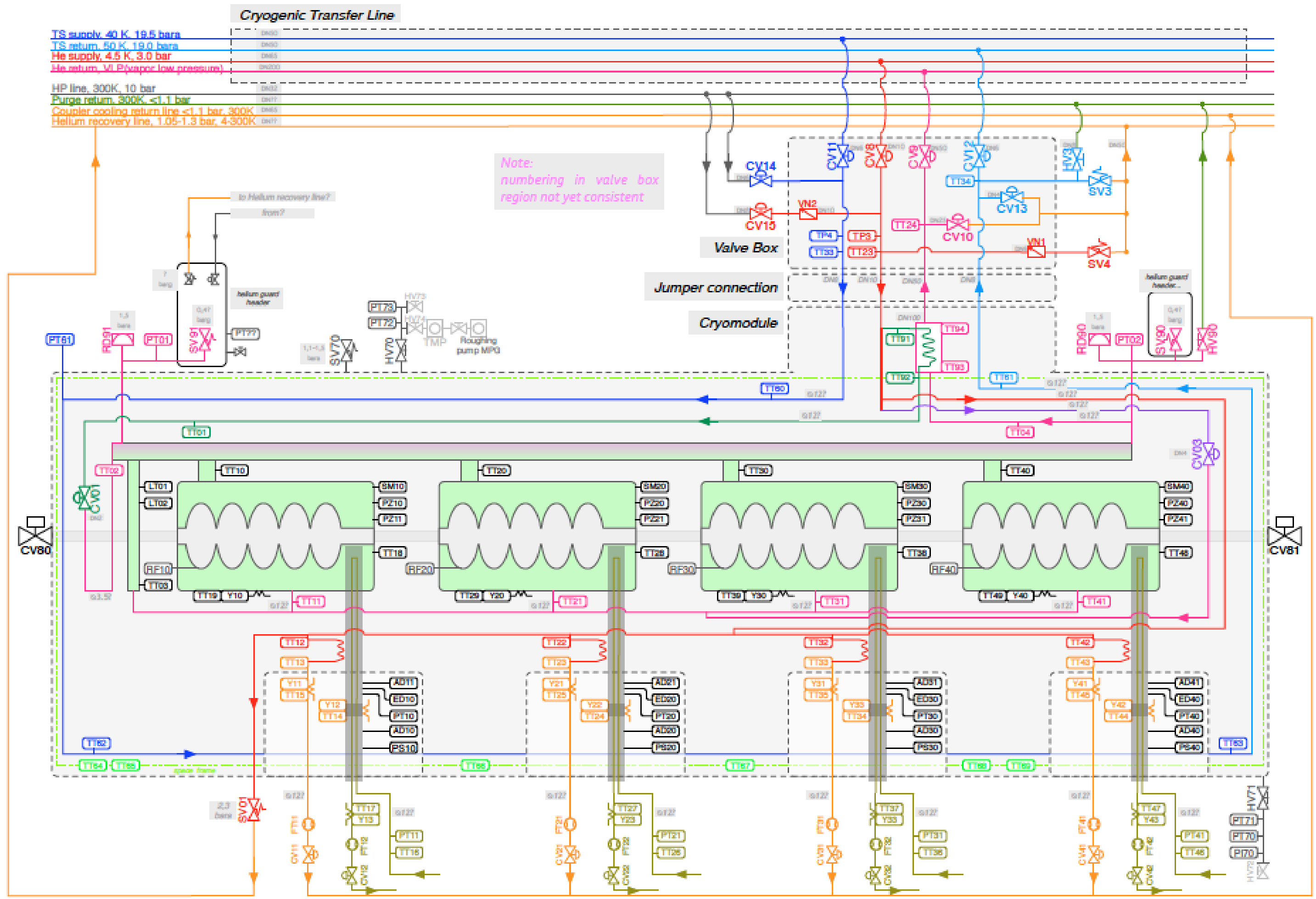
Figure 1. ***ITER cryogenic distribution system.*** Image reprinted, with permission of AIP Publishing, from S. Badgujar et al., "Progress and Present Status of ITER Cryoline System," *Advances in Cryogenic Engineering*, Vol. 59A, 2014 (doi.org/10.1063/1.4860792).

Distribution System Example : ESS

Cryogenic System of the Optimus Linac



Connection between Elliptical Cavity CM and Cryogenic Distribution Line



Version 20140227a NE

Allows independent CD/WU of cryomodules

CDS-EL Components installation in Tunnel

Distribution System Example : LCLS II

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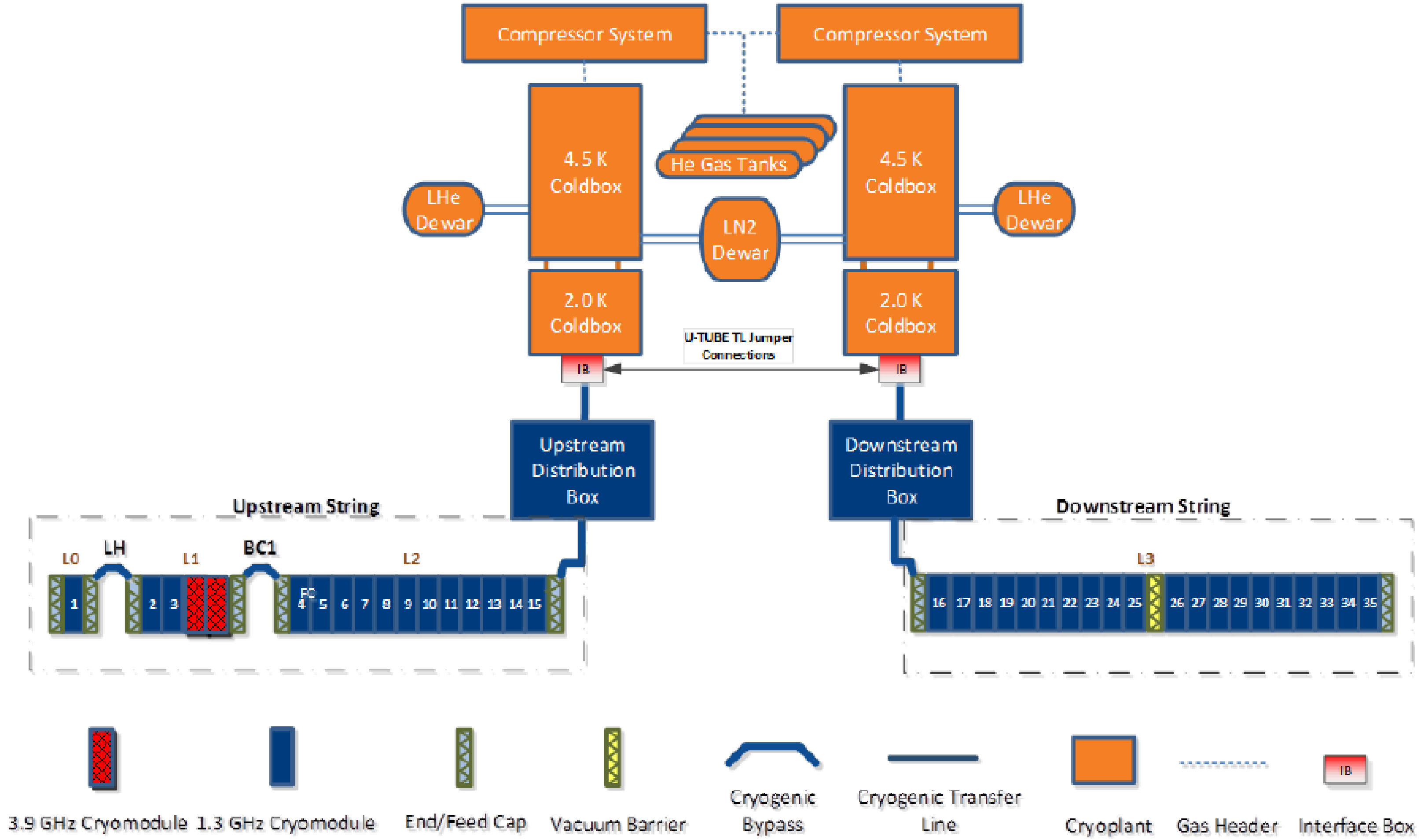
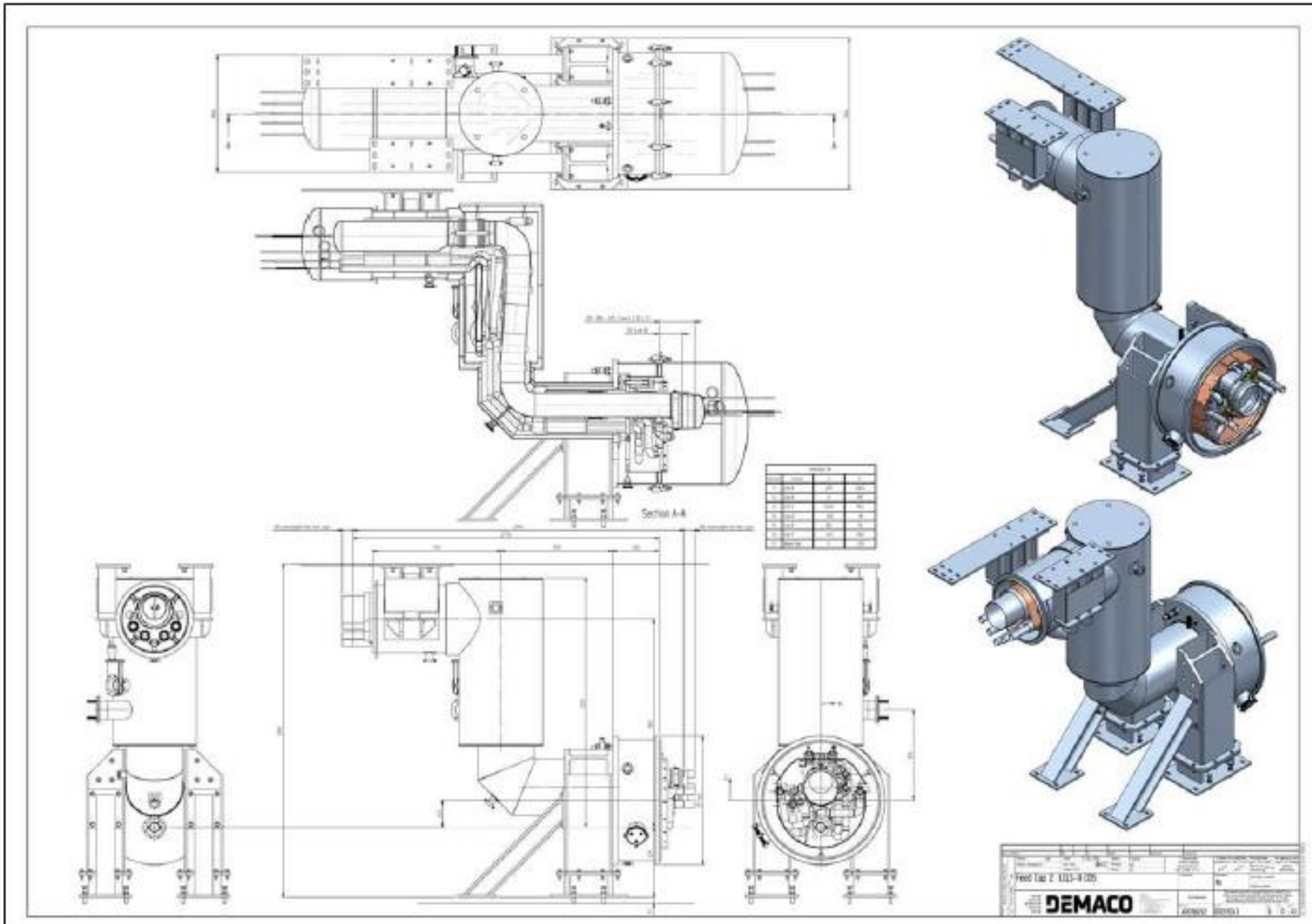
LCLS-II Cryogenic Distribution



LCLS II Feedcaps 2 and 4
A. Klebaner (FNAL) & DEMACO



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LCLS-II end box, transfer line, and distribution box at SLAC

Distribution or Valve Boxes

- Provide connections between cryoplants, components to be cooled and transfer lines
- End Boxes and Feed Boxes at the ends of cryogenic sections
- Generally complicated, custom designed components. They may contain:
  – Valves: control, shut off, relief etc
  – Heat exchangers
  – Liquid reservoirs
  – Heaters
  – Instrumentation
  – Current leads
  – Connections to warm systems

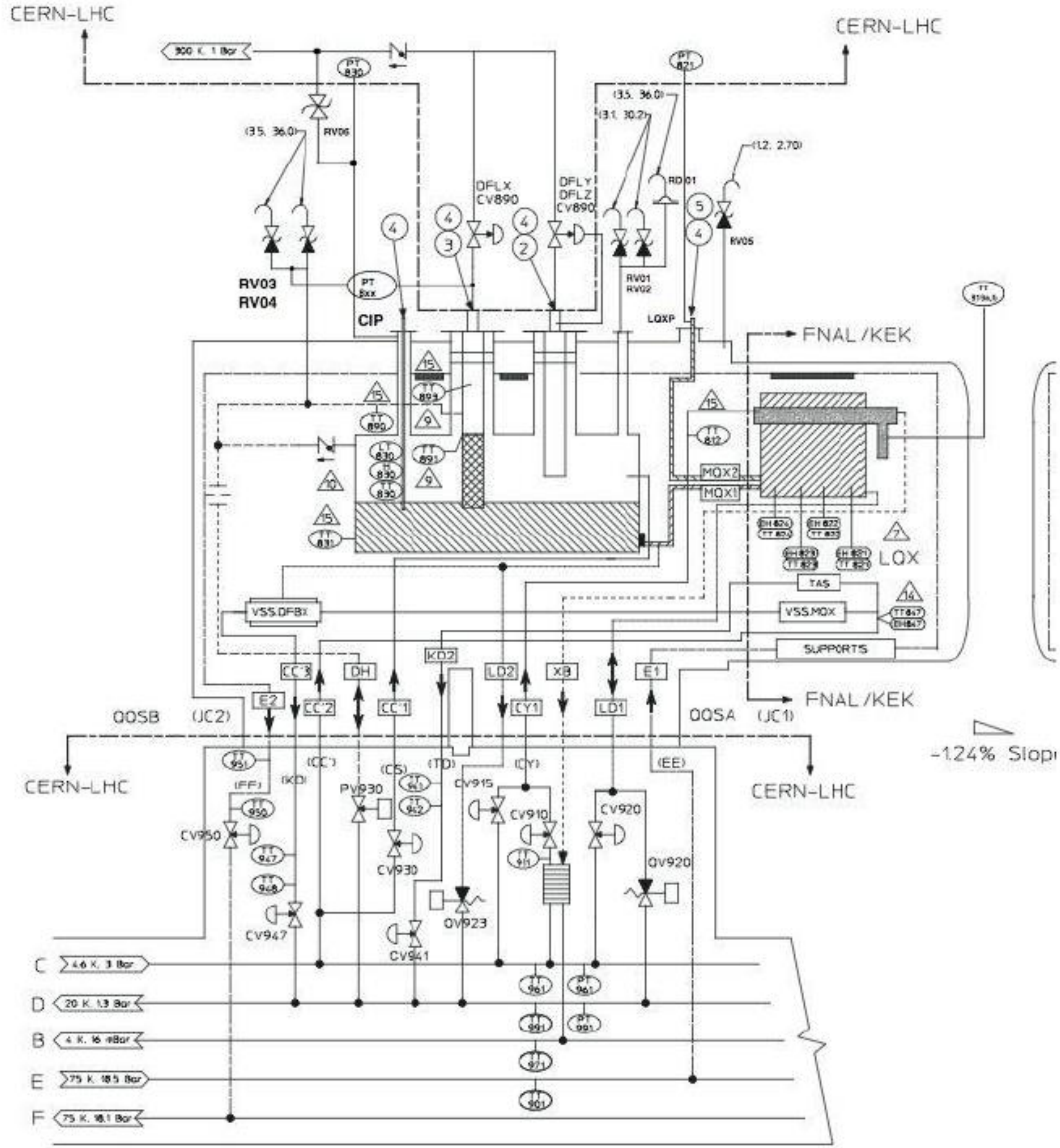
Example # 1

LHC test string 2 feed box (CERN)

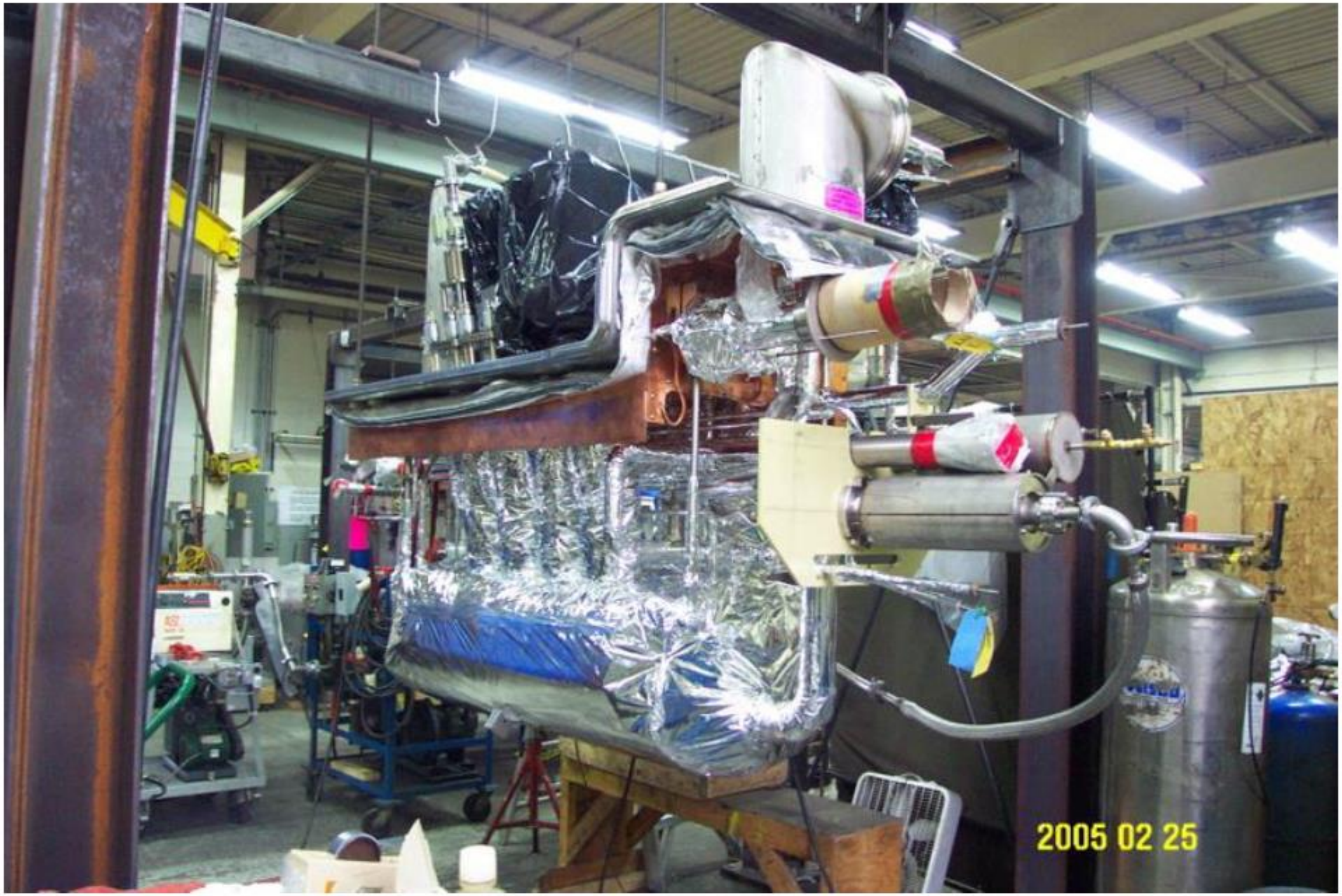
Many current leads and ports for access to make splice joints

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


CERN-LHC
300 K, 1 Bar
PT 830
PT 821
RV06
(3.5, 36.0)
(3.1, 30.2)
(1.2, 2.70)
DFLX CV890
DFLY DFLZ CV890
RD01
RV05
RV03
RV04
PT 8xx
RV01 RV02
CIP
LQXP
FNAL/KEK
MQX2
MQX1
LQX
TAS
VSS.DFBX
VSS.MQX
SUPPORTS
CC'3
DH
KD2
LD2
XB
E1
E2
CC'2
CC'1
CY1
LD1
QQSB
(JC2)
QQSA
(JC1)
-1.24% Slop
(CC')
(KD)
(FF)
(CS)
(TD)
(CY)
(EE)
PV930
CV915
CV910
CV920
CV950
CV930
QV920
QV923
CV947
CV941
C 4.6 K, 3 Bar
D 20 K, 1.3 Bar
B 4 K, 16 mBar
E 75 K, 18.5 Bar
F 75 K, 18.1 Bar

DFBX Under Construction



Conclusions

- Transfer lines, distribution systems and valve boxes are an important part of cryogenic systems
- They have unique challenges and may be quite complex
- They can constitute a significant amount of both cost and schedule
- Do not under estimate the amount of time and money to successfully create these components
- Full scale prototyping say in a test facility is highly advised to reduce risk.