Lecture 9
Cryostat Design (Part II)

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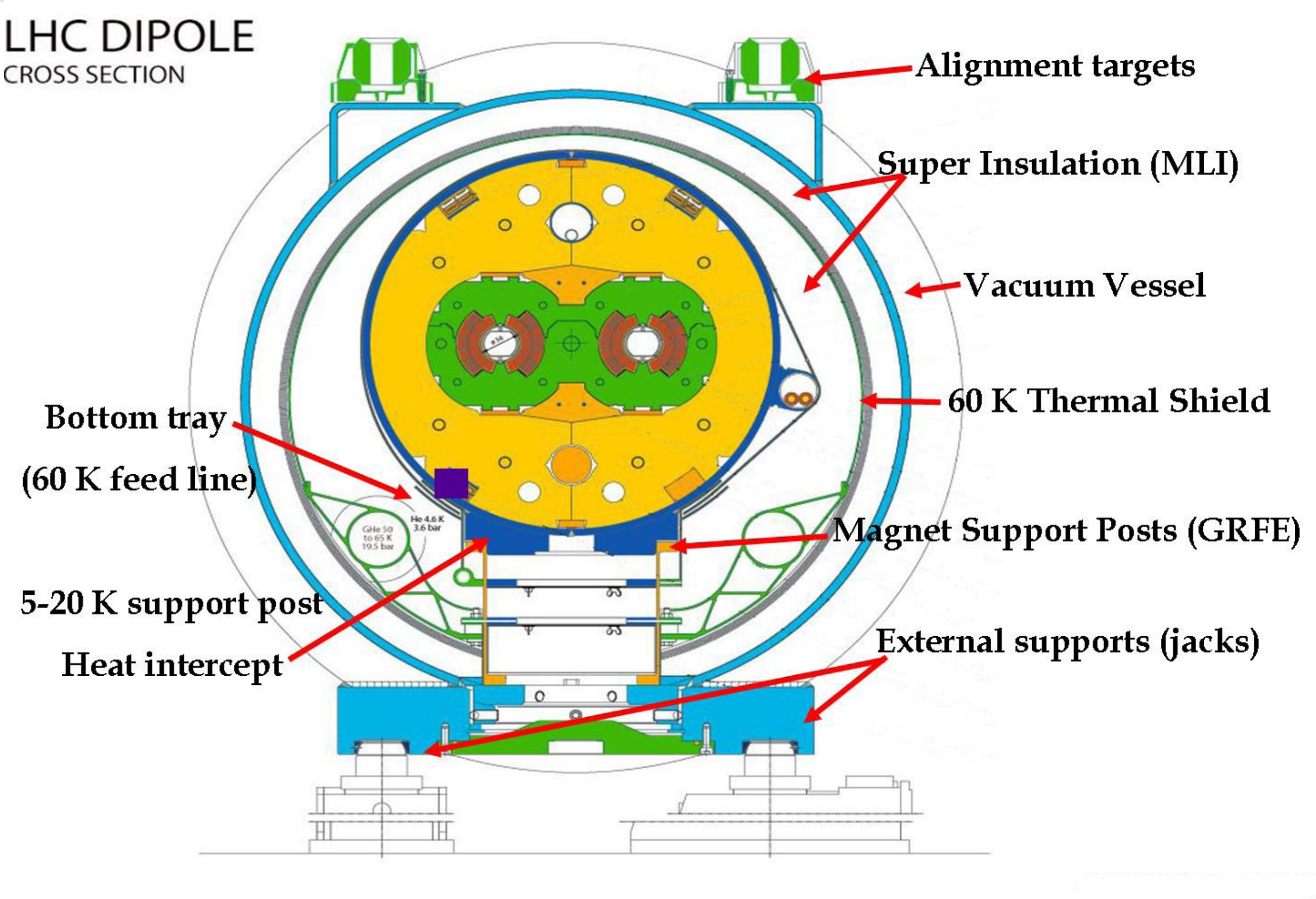
Goals

- Describe aspects of cryostat design via example

Example #1: LHC Dipole Cryostat

- Some key requirements
  - 1232 cryostats required
  - High reliability
  - 1.9 K (He II) cooled magnets
  - Low per unit heat leak
  - Minimize cost of materials & assembly
- Design Choices
  - Vacuum vessel dimensions chosen to meet industry standard tube sizes
  - GFRE support posts with heat intercepts at 60 K and 5 K
  - Simple integrated aluminum heat shields at 60 K
  - No 5 K radiation shield but MLI blankets between 300 K and 60K and between 60 K and 1.9 K
  - Almost all seals are done via welding with strict QA program
  - Minimal instrumentation
  - Final assembly at CERN via contractor

LHC Dipole Cross Section



Alignment targets

Super Insulation (MLI)

Vacuum Vessel

60 K Thermal Shield

Bottom tray

(60 K feed line)

Magnet Support Posts (GRFE)

5-20 K support post

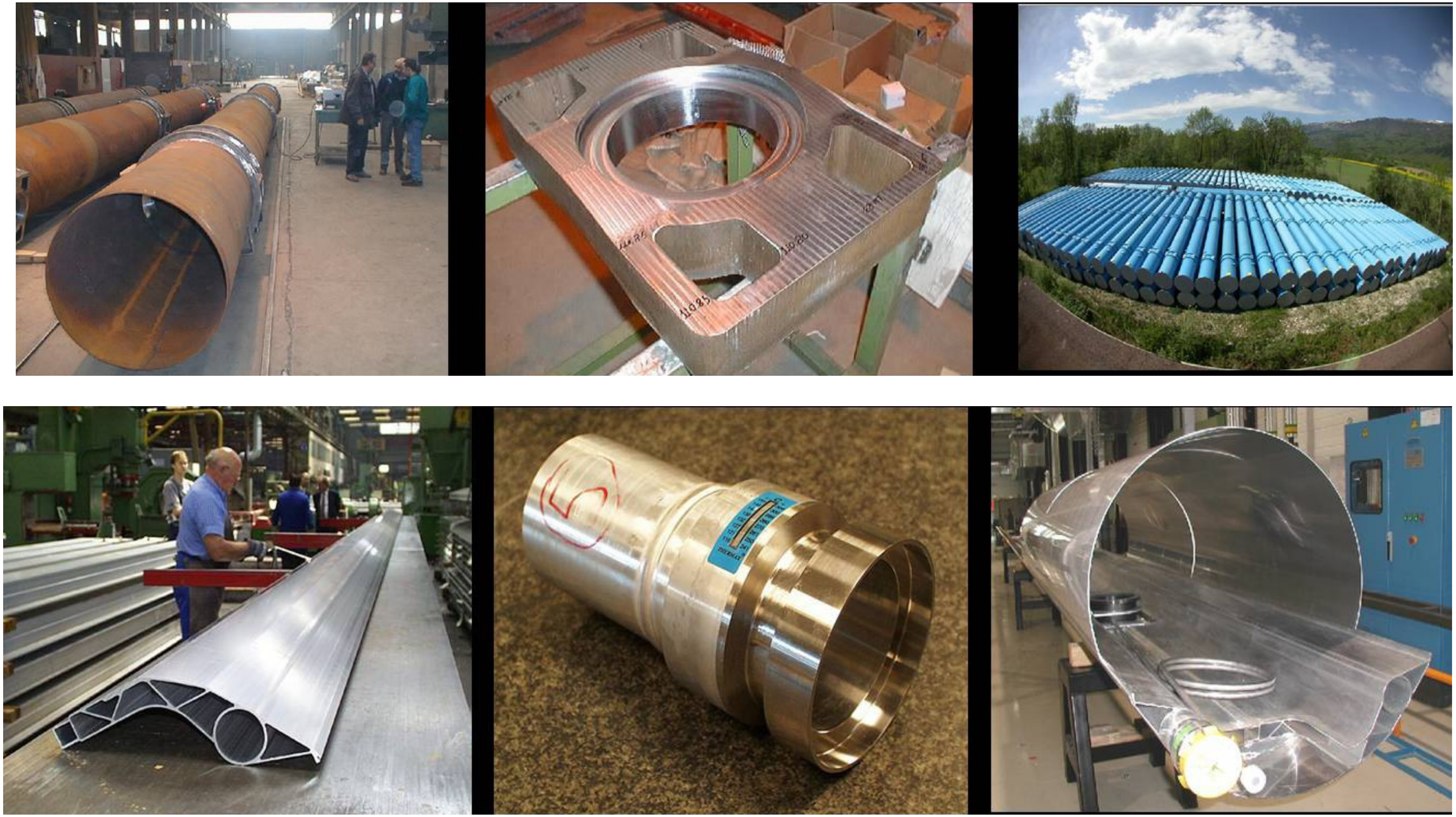
Heat intercept

External supports (jacks)

“SERIES-PRODUCED HELIUM II CRYOSTATS FOR THE LHC MAGNETS: TECHNICAL CHOICES, INDUSTRIALISATION, COSTS” A. Poncet and V. Parma Adv. Cryo. Engr. Vol 53

LHC CROYOSTAT COMPONENTS

"SERIES-PRODUCED HELIUM II CRYOSTATS FOR THE LHC MAGNETS: TECHNICAL CHOICES, INDUSTRIALISATION, COSTS" A. Poncet and V. Parma Adv. Cryo. Engr. Vol 53



LHC Dipole Cryostats

- Cost per unit (not including cold mass)
  ~ 100 kCHF (2007 value)
  Compare to 1996 estimate of 130 kCHF (2007 value)
- Largest single cost component is the vacuum vessel at 35.2%
- QA program was 2.4% of unit cost
- Current status: all cryostats delivered, accepted, and cold. LHC currently conducting physics

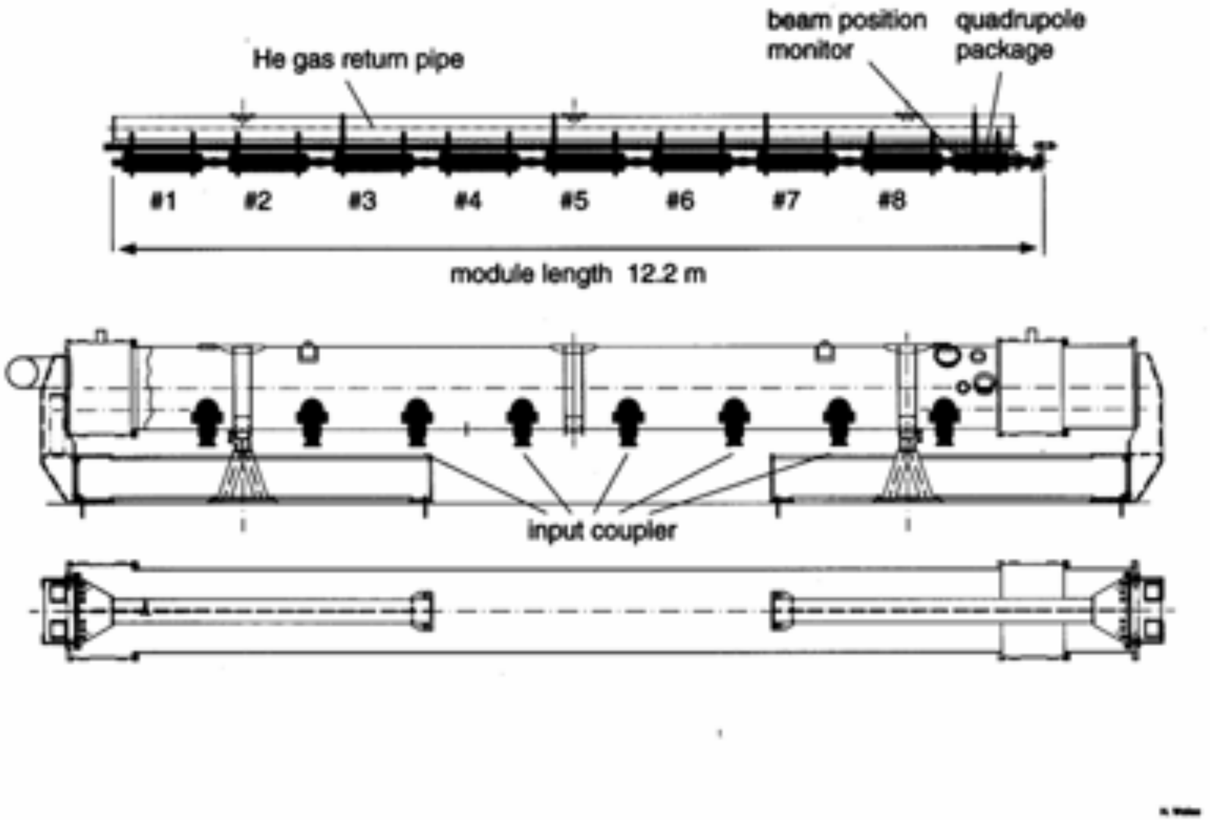
Example #2 International Linear Collider SCRF Cryomodule

- Two 15 km long linacs (250 GeV on 250 GeV)
- 35 MV/m SCRF cavities (1.3 GHz)
- Requires ~ 2000 cryomodules
- Extension of TESLA technology
- Requirements are very similar in many ways to LHC dipoles
  - ILC cryomodules have much higher dynamic heat loads

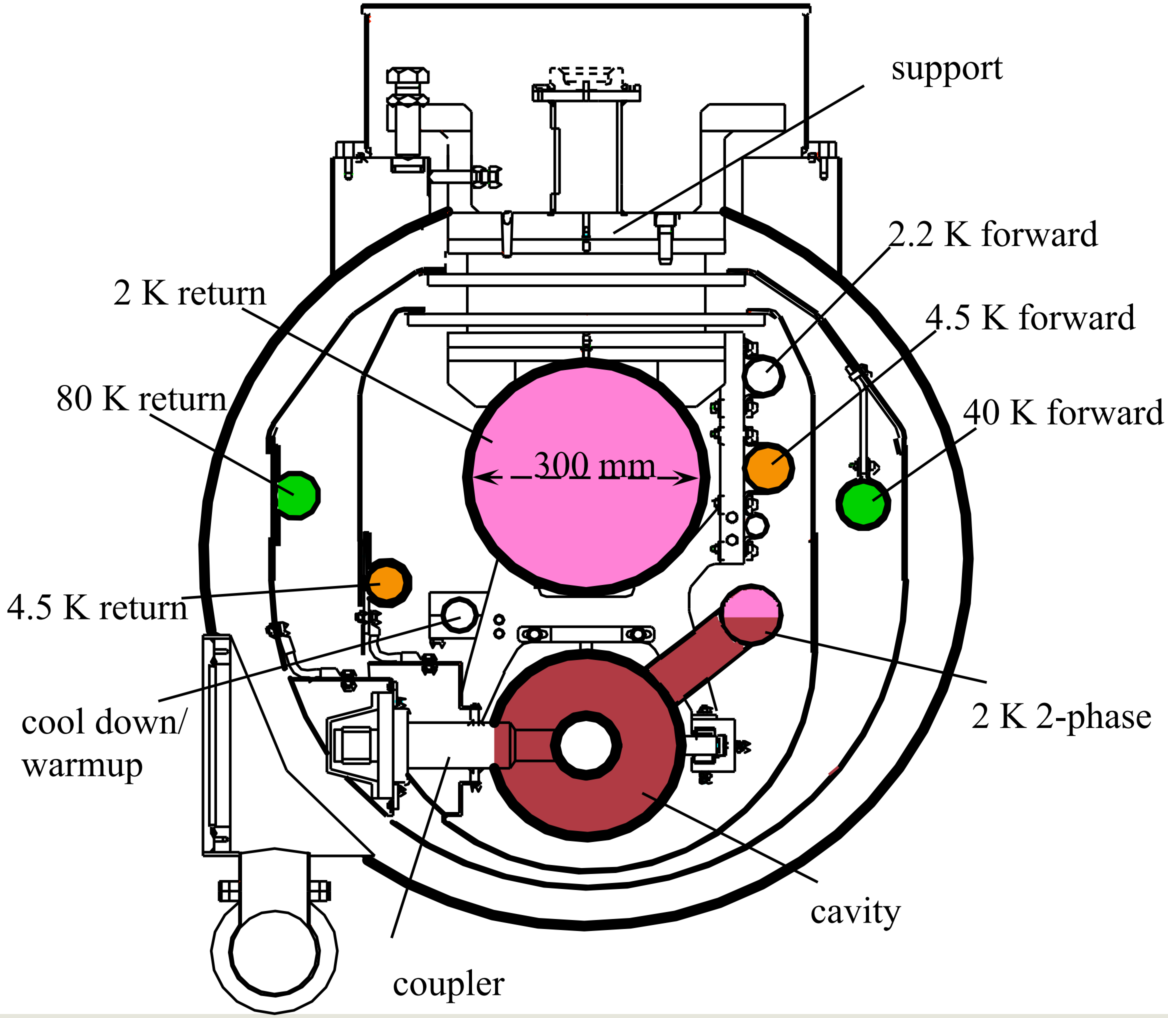
ILC Cryomodule Features

- Eight 9 cell sc cavities + possibly 1 sc magnet package
- Components are tied to 300 mm pipe strongback
- 2 thermal shields (40/80 K and 5 K)
  - 5 K may go away during value engineering
- New design allows semi-fixed couplers
- Design has been extensively tested during the TESLA project
- ILC design is a fourth generation of the TESLA cryomodu

Side View of 1st Generation TESLA Cryomodule (each end of 300 mm tube shrinks 15 mm upon cooldown)



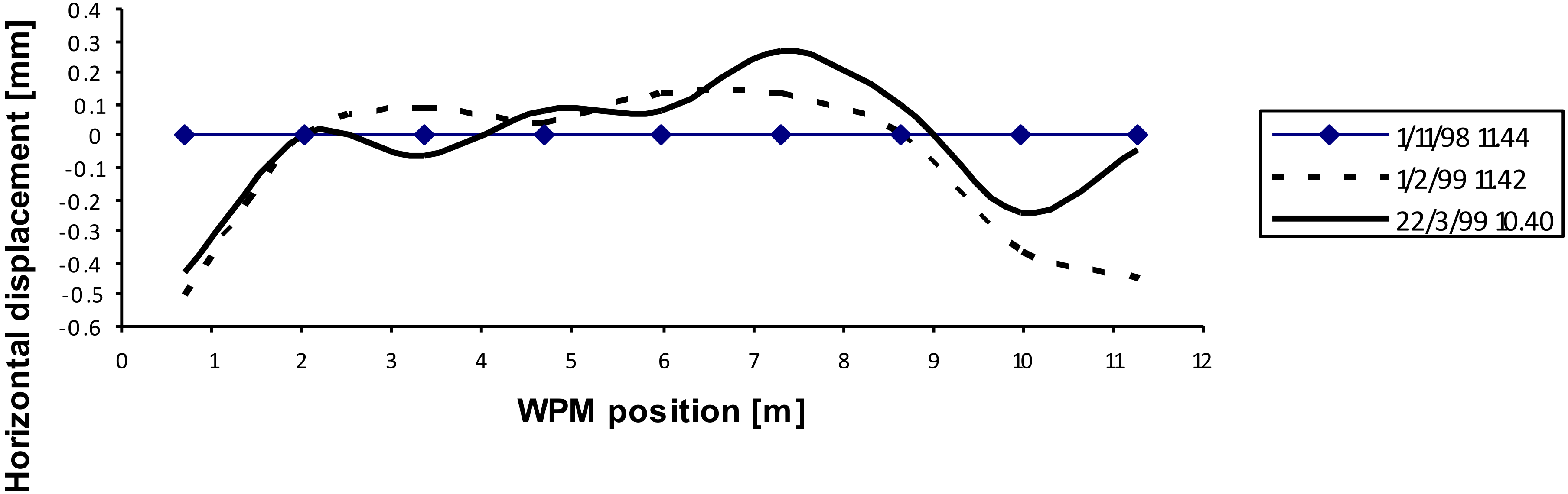
3rd Generation TESLA Cryomodule
ILC Prototype



TESLA Static Heat Leak Measurements (note total 2 K heat load is ~ 7 W)

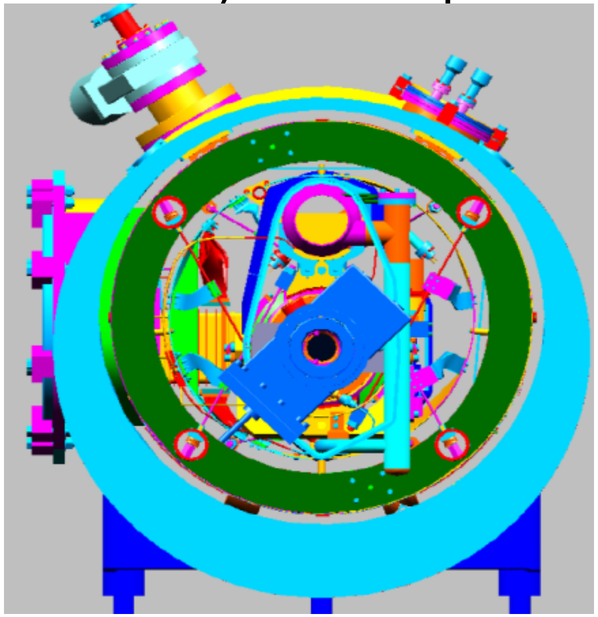
Temperature Level	Predicted Heat Leak (W)	Measured Heat Leak (W) Cryomodule #1 (alone)	Measured Heat Leak (W) Cryomodule #1 (with #2)	Measured Heat Leak (W) Cryomodule #2
70 K	76.8	90	81.5	77.9
4.5 K	13.9	23	15.9	13
2 K	2.8	6	5	4

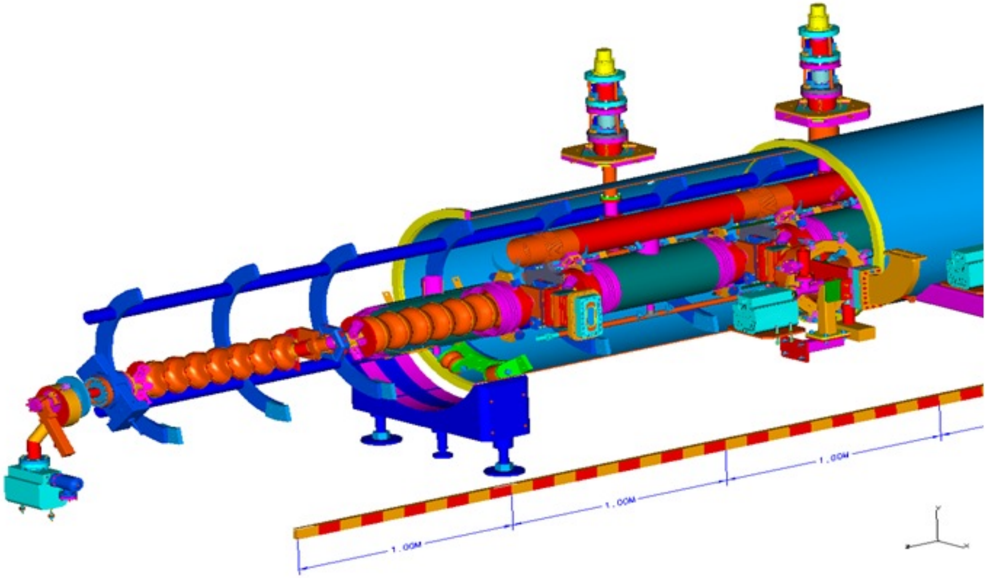
Alignment Results Cryomodule 2



Example 3
JLab 12 GeV Upgrade Cryomodule

- Based on successful SNS design - a total of 10 CMs were needed
- Cavities at 2.1 K, thermal shield at 50 K – no s/c magnets present
- Cold Mass tied to space frame via nitronic rods
- Space frame rolls into vacuum vessel
- Despite extensive SNS experience, design changes (mainly in cold mass) were required after 1st prototype – *value of prototyping*

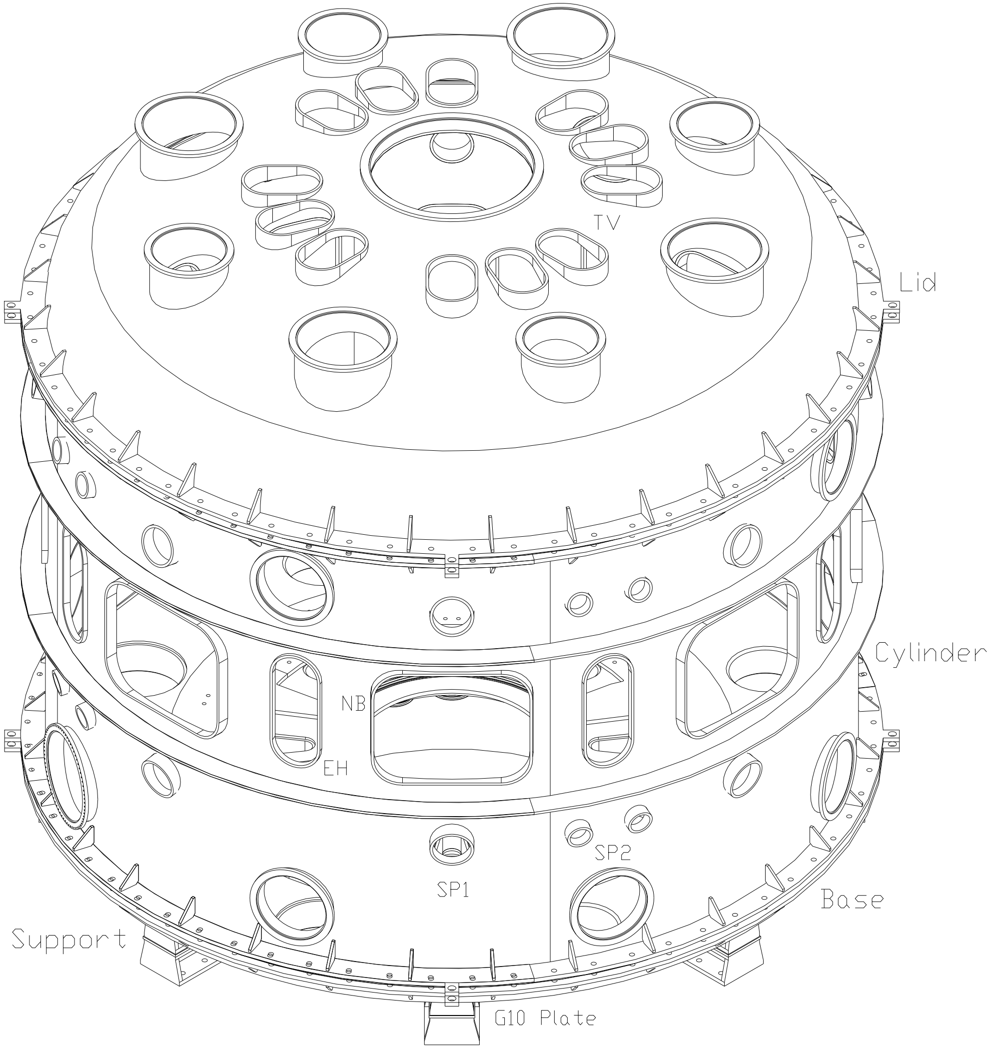




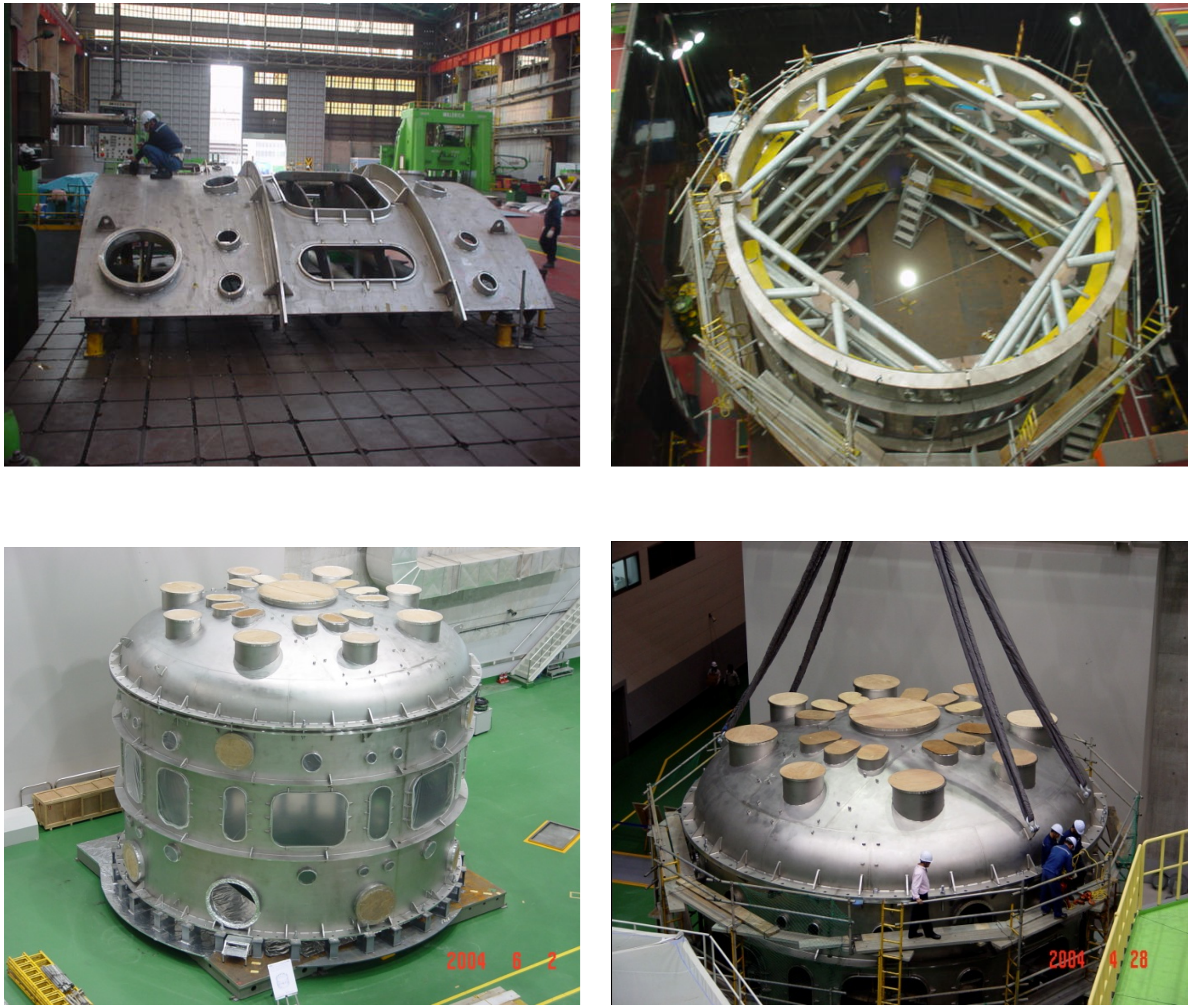
Example #4
Cryostat and Thermal Shield for KSTAR (Korea Superconducting Tokamak Advanced Research)

- Large (~ 9 m diameter Tokamak using superconducting magnets)
- S/C magnets are contained in a single cryostat (8.8 m ID and 5.7 m high)
- Cryostat is very complex with 72 penetrations
- Designed to ASME pressure vessel code

KSTAR Vacuum Vessel



Vacuum Vessel Fabrication



KSTAR Thermal Shield

- Intercepts thermal radiation from 300 K surfaces
- Actively cooled by He gas to ~ 80 K
- Three classes of shields Cryostat (CTS), Vacuum Vessel (VVTS) and Port (PTS)
  - Space is very limited for VVTS and PTS so MLI blankets are not possible but surfaces were silver plated to improve emissivity

KSTAR Thermal Shield; Recent Progress

2007 IAEA

G. H. Kim, W. C. Kim, H. L. Yang, C. H. Choi, J. S. Bak (NFRC)
D. K. Kang (Wonshin Eng.)

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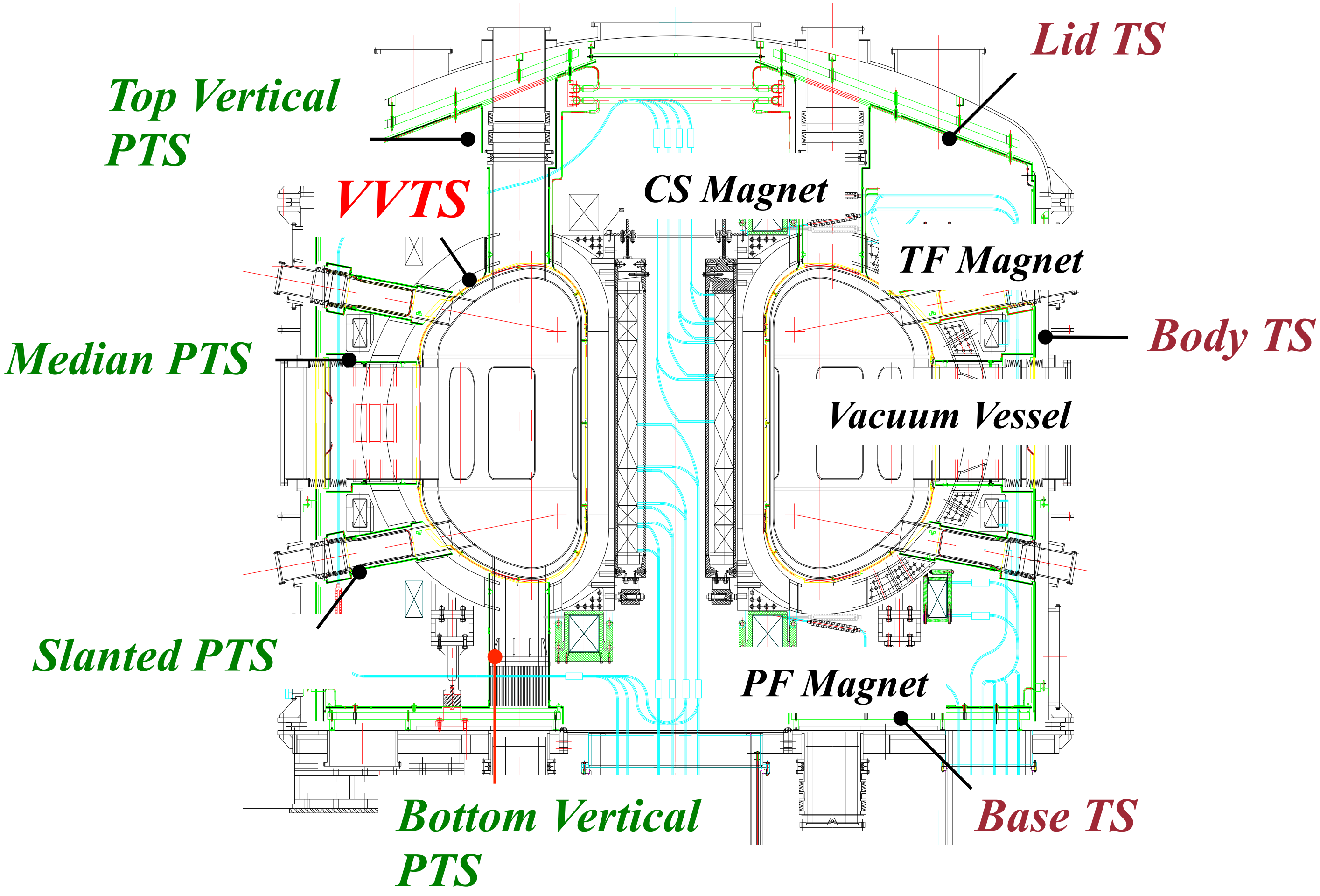
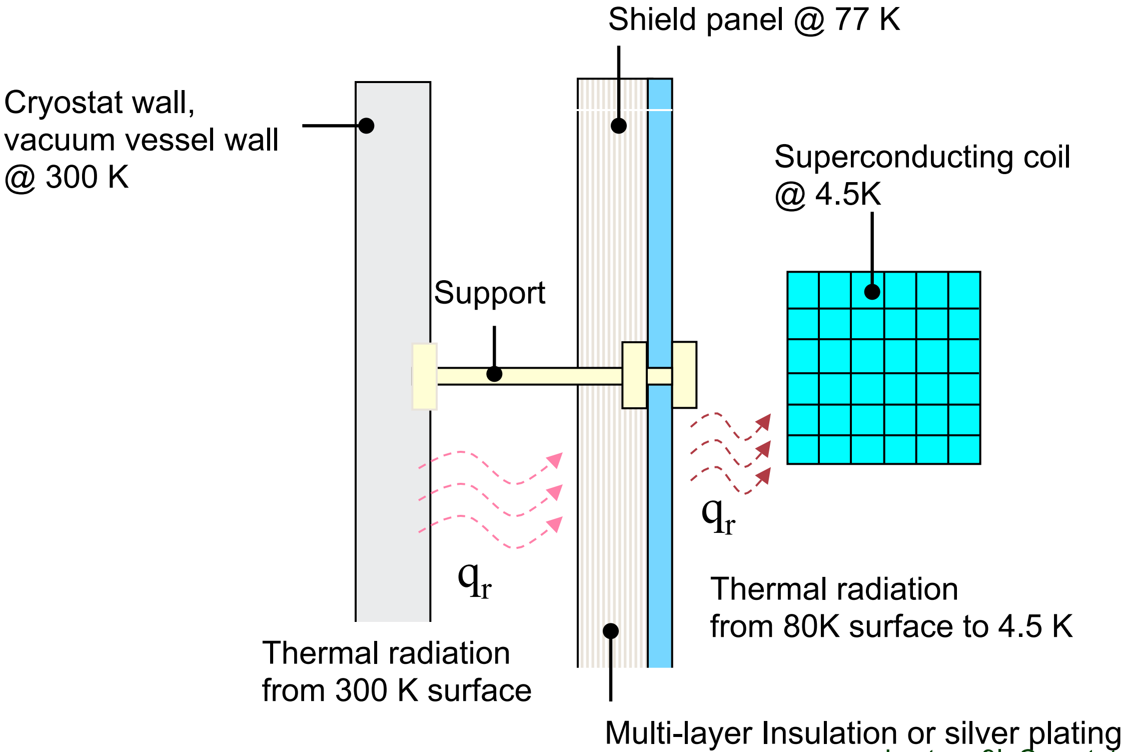
National Fusion Research Center

Thermal Shield Locations



KSTAR Thermal Shield

- **KSTAR thermal shield** intercepts radiation from 300 K to 4.5 K and contributes to economic operation of refrigerator system.
- Consists of three categories: vacuum vessel thermal shield (VVTS), port thermal shield (PTS), and cryostat thermal shield (CTS).
- Tube on panel configuration is a basic shape of the KSTAR TS.



Shield panel @ 77 K

Cryostat wall,
vacuum vessel wall
@ 300 K

Superconducting coil
@ 4.5K

Support

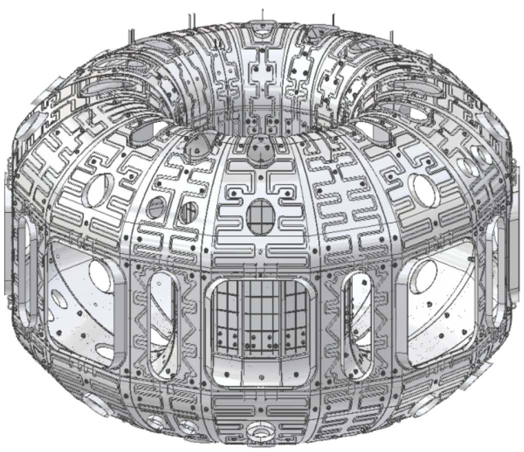
Thermal radiation
from 80K surface to 4.5 K

Thermal radiation
from 300 K surface

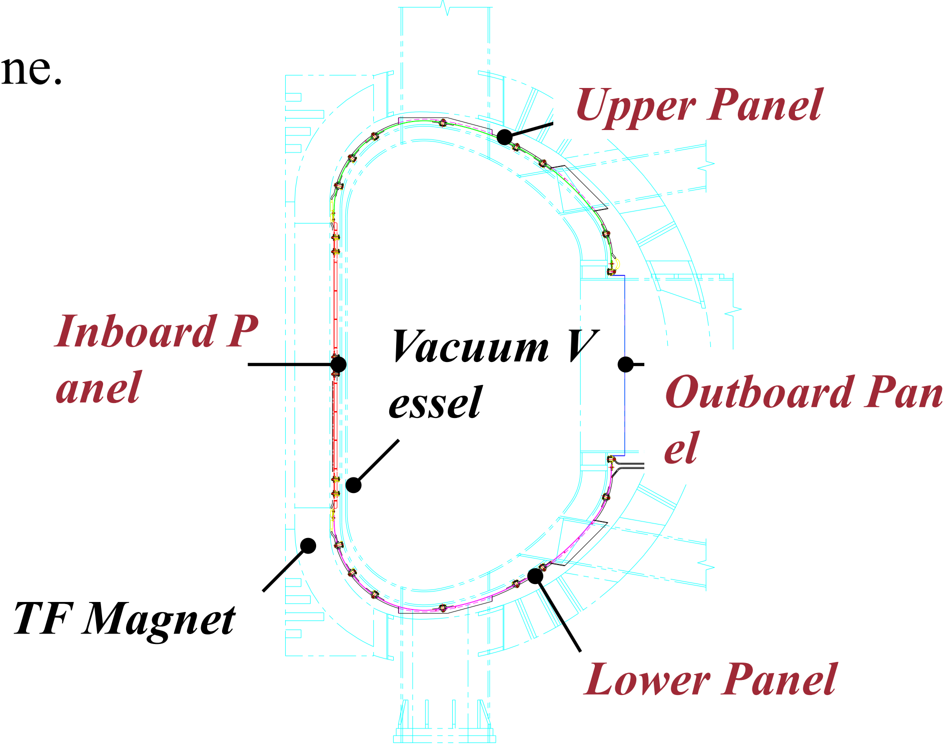
Multi-layer Insulation or silver plating

Vacuum Vessel Thermal Shield

- ❑ **VVTS** is toroidally segmented into 16 sectors and poloidally partitioned into 4 pieces.
- ❑ Shield panel is plated by silver of 10 ㎛ thickness instead of using multi-layer insulation (MLI) due to narrow gap.
- ❑ VVTS has redundancy cooling line.



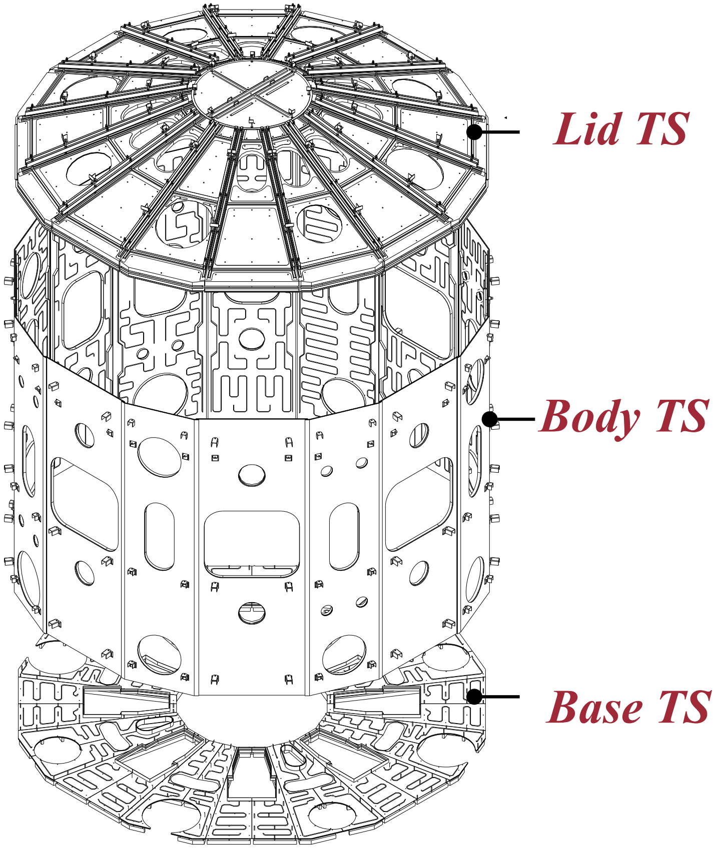
Isometric view of vacuum vessel thermal shield



Four sub-sectors in poloidal direction

Cryostat Thermal Shield

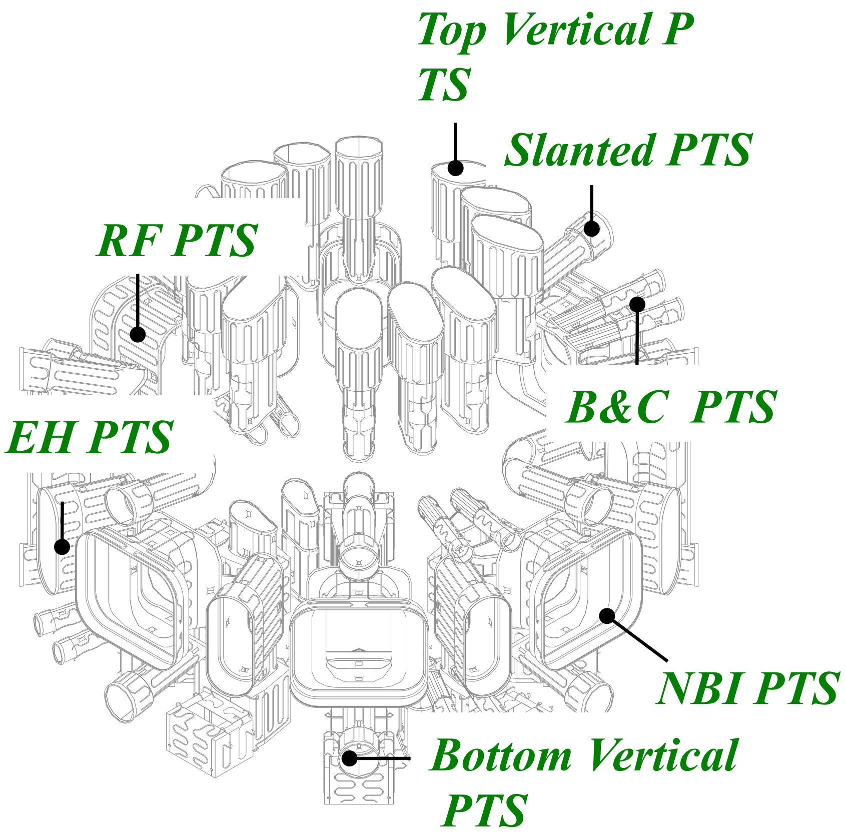
- ☐ **CTS** is placed on the cryostat inner surface wall.
- ☐ MLI is adopted to prohibit thermal radiation from cryostat surface.
- ☐ Each part is toroidally divided into 16 sectors.
- ☐ Shield panel consists of a flat stainless plate, MLI of 30 layers, 1 mm thick stainless steel sheet, and G10 spacers.



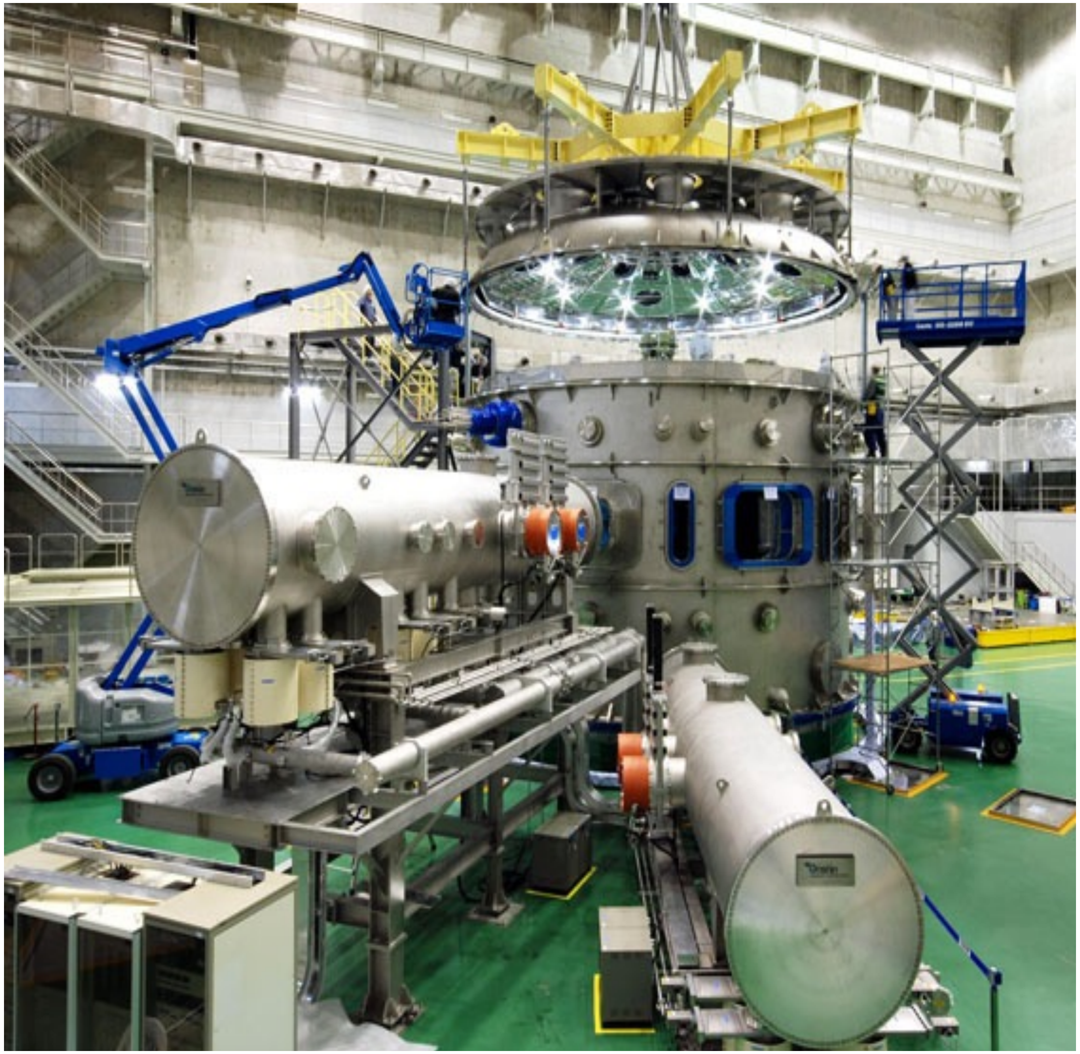
Exploded view of cryostat t hermal shield

Port Thermal Shield

- There are 72 penetration ports for connecting the vacuum vessel body and cryostat.
- Ports are classified into 7 types: NBI, EH, RF, SL, B&C, TV, BV port.
- **PTS** covers all of ports.
- Silver plating method is adopted for the PTS.
- All PTSs are divided into two parts: lower and upper part.



Isometric view of port thermal shields



KSTAR Thermal Shield; Recent Progress
G.H. Kim, W.C. Kim, H.L. Yag, C.H. Choi, J.S.Bak, D.K. Kang

Example #5 Space Cryostat
The X-Ray Spectrometer (XRS)

- Mission life time is dependent on the supply of He II (1.3 K) in the cryostat. In order to achieve the 2.5 year life time, the heat leak must be < 800 μW
- Additional design drivers:
  - Size and weight
  - Use of an ADR requiring a superconducting magnet – sensors need 0.065 K
  - A costly one of a kind device

Solutions to Minimize Heat Leak

- All heat leaks (even 10 μW) are important
- Solid Ne (17 K) dewar surrounds He dewar to reduce radiation and conduction heat leak
- Low emissivity materials used: polished Al, gold plating and aluminized mylar
- HiT$_c$ superconductors used for magnet leads
- All other wiring is optimized for minimum heat leak
- Helium tank suspended by graphite/epoxy straps optimized to meet launch loads
- Radiation baffles in vent and fill lines plus devices to prevent superfluid film flow in vent line

“Thermal Design of the XRS Helium Cryostat”, S. Breon et al., Cryogenics 36:10 (1996)

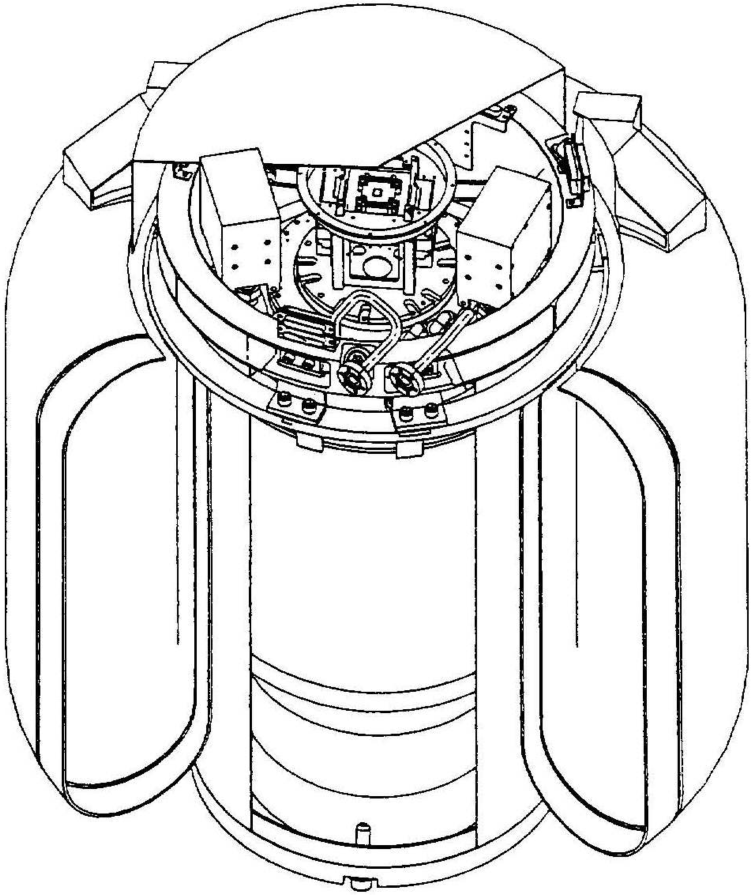


Figure 1 XRS configured for Astro-E. Hybrid cyrogenic system provides cooling stages at 17 K (solid neon), 1.3 K (superfluid helium) and 0.065 K (ADR). JFETs in FEA are at 80–120 K

"Thermal Design of the XRS Helium Cryostat" S. Breon et al., Cryogenics 36:10 (1996)

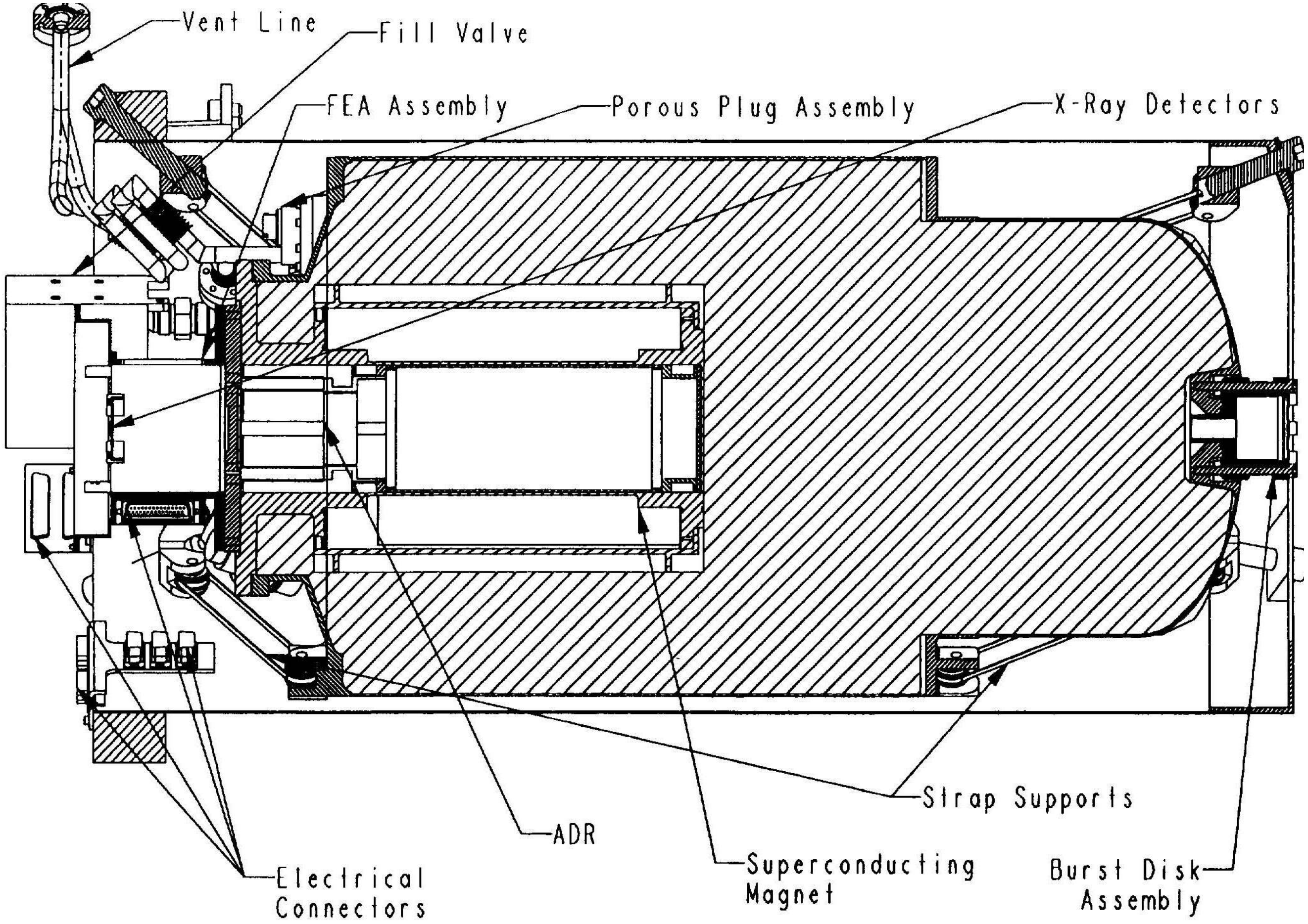


Figure 2 XRS helium cryostat

XRS Cryostat

- Analytical heat leak models and full scale thermal measurements at the component, subsystem and helium insert level were carried out.
- Measured heat leak to the helium insert (on the ground) was ~ 629 μW

Tips for Successful Cryostat Design

- Define requirements first
- Design in safety from the start
- Use appropriate materials for cryogenic temperatures
- Review literature & learn from previous efforts
- Use tested commercial solutions whenever possible
- Avoid feedthroughs & demountable seals at cryogenic temperatures
- Conduct prototype tests when required