Magnetic Radiation Shielding for Space Exploration

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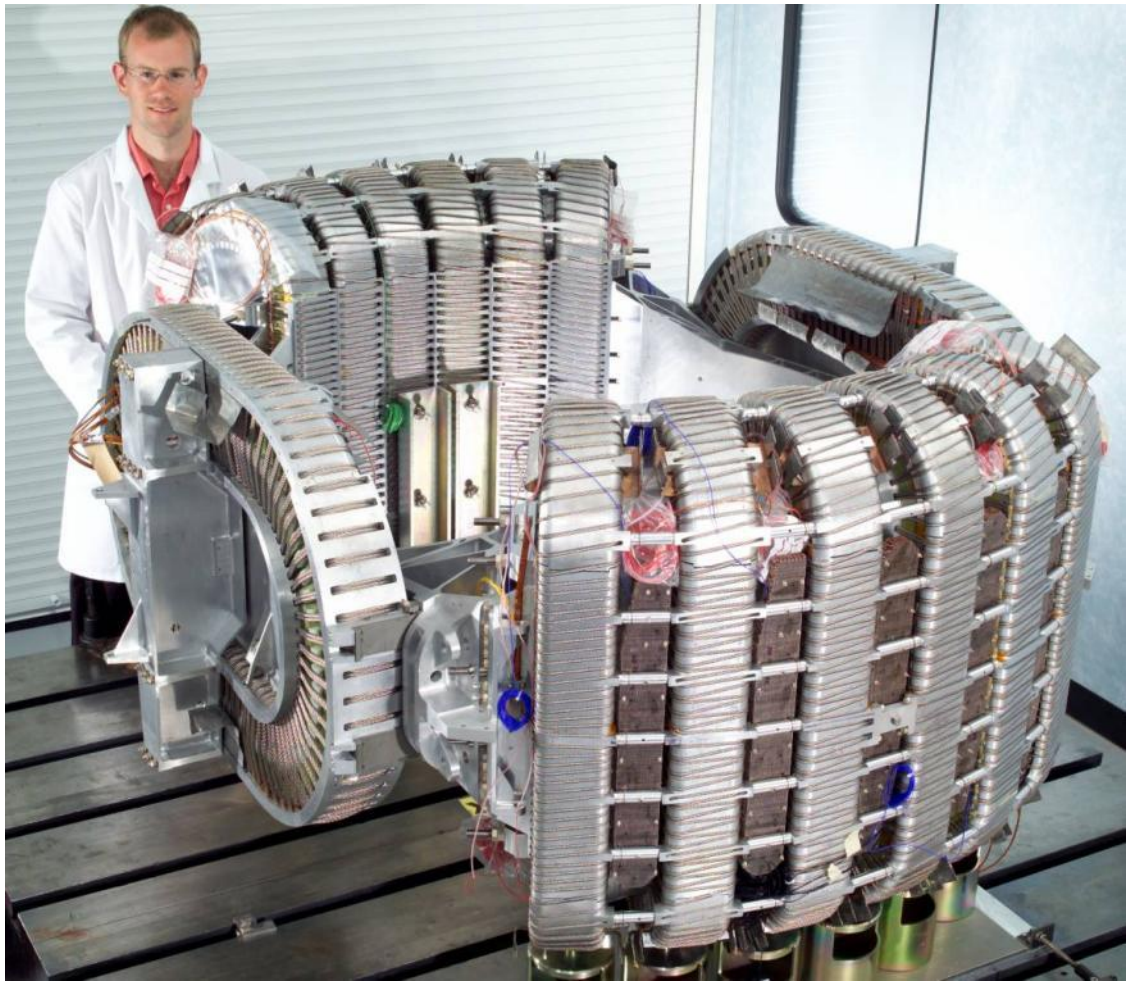
AMS Superconducting Magnet



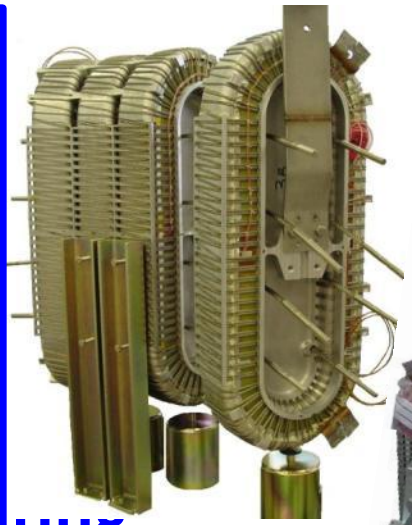
SCIENTIFIC MAGNETICS

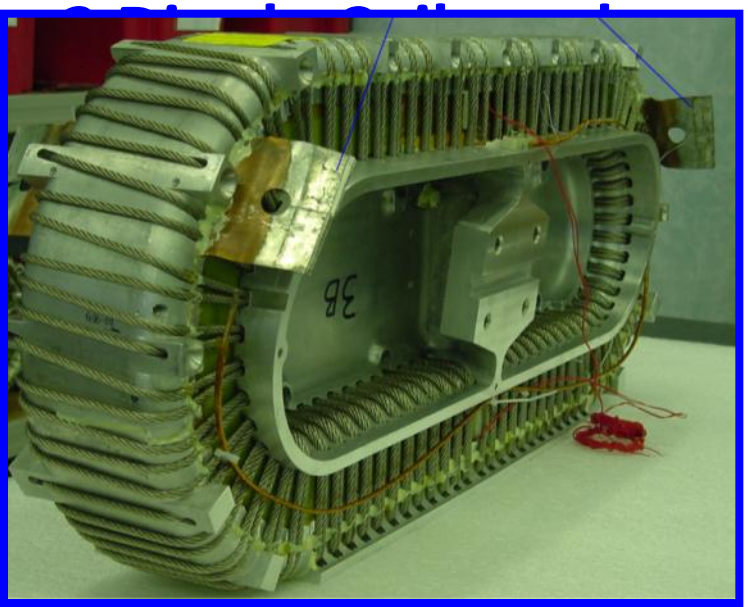
The Alpha Magnetic Spectrometer (AMS) Superconducting Magnet is the only large superconducting magnet designed for use in space. It was built by Scientific Magnets near Oxford, England.

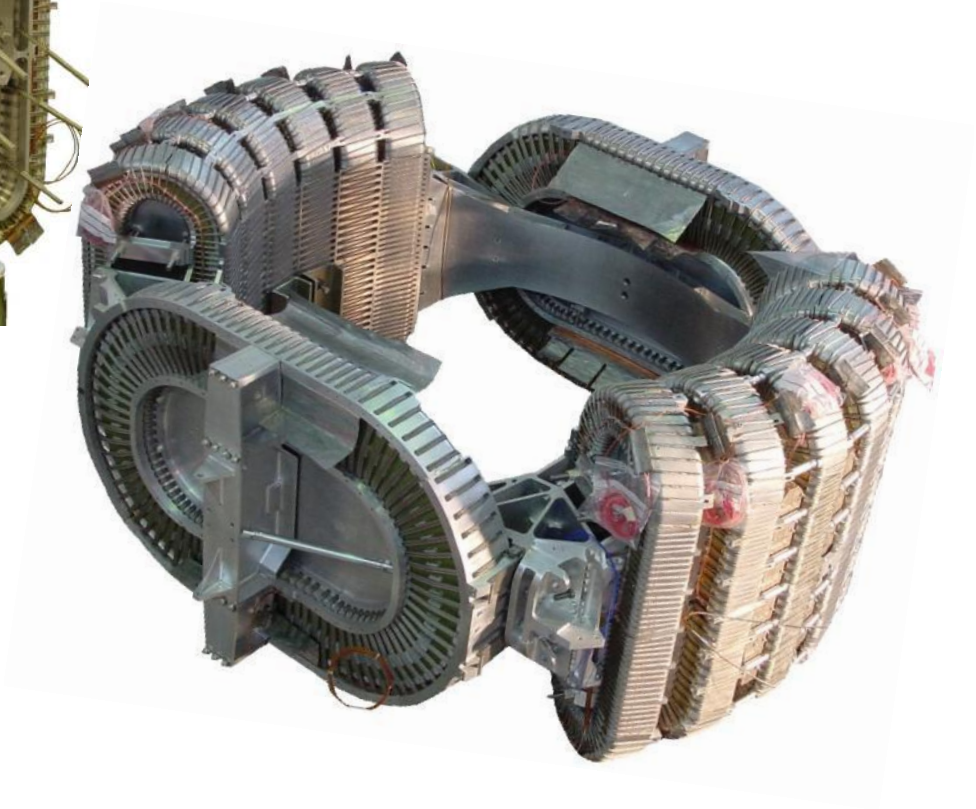
AMS Low Temperature Superconductor

The aluminium-stabilised NbTi Low Temperature Superconducting wire was developed for the AMS Magnet by ETH-Zurich

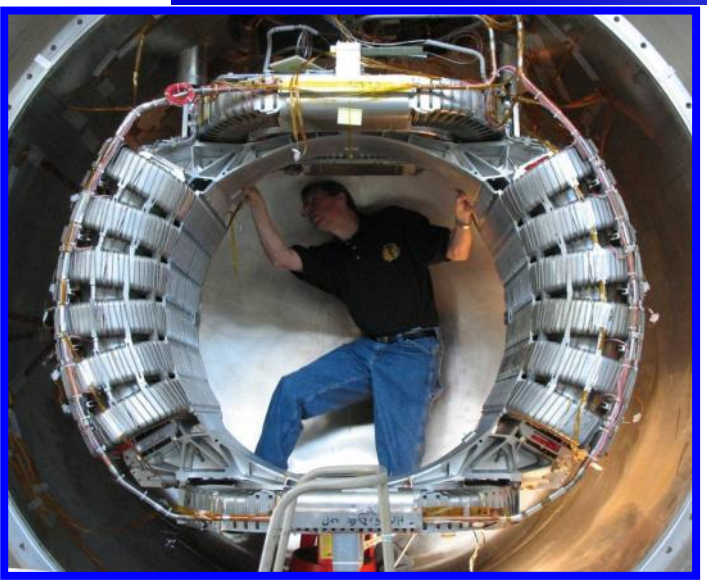
AMS Superconducting Magnet

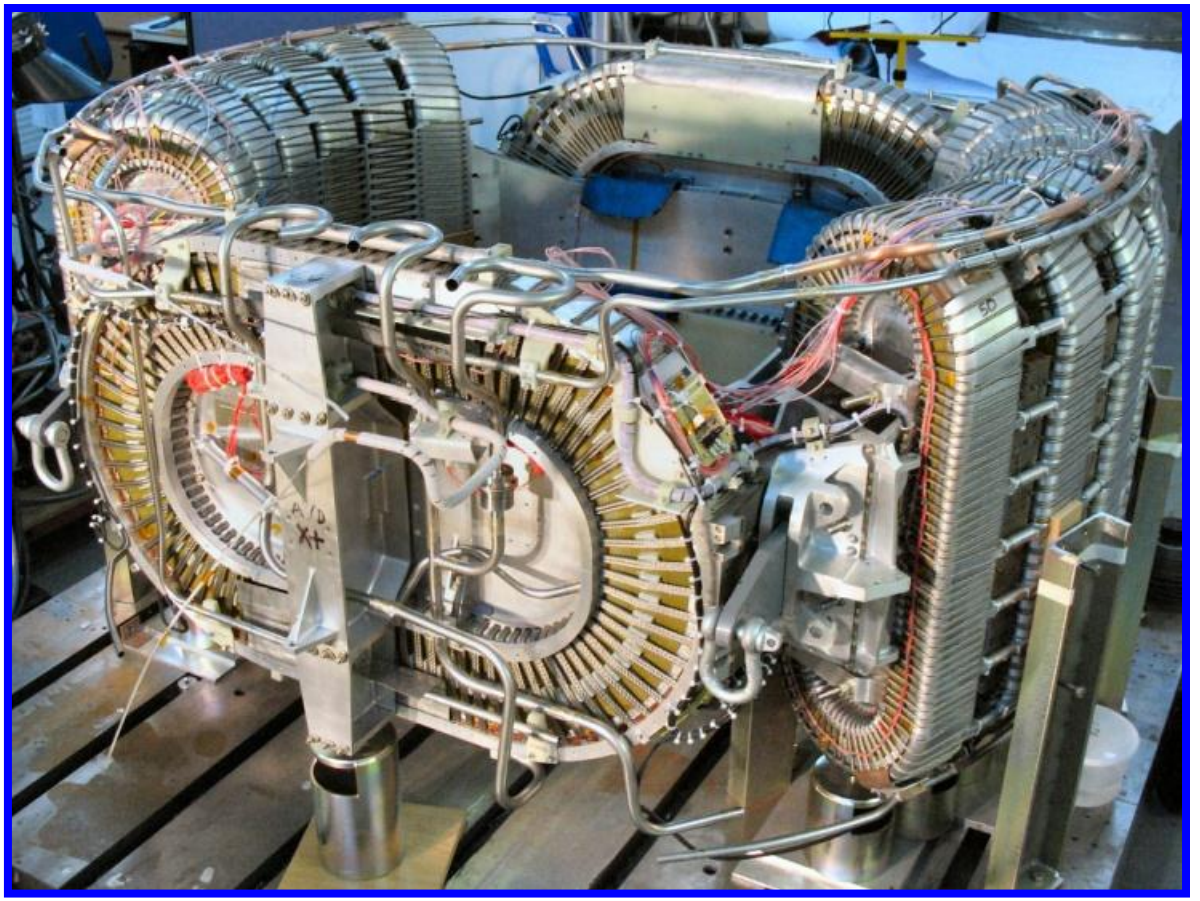






AMS Superconducting Magnet

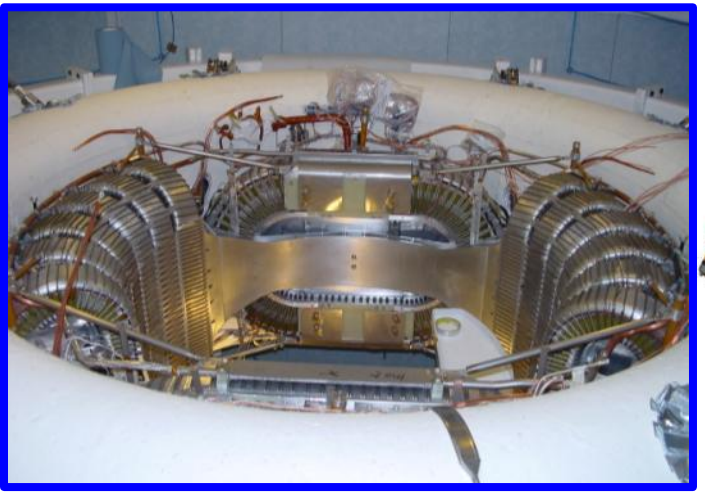


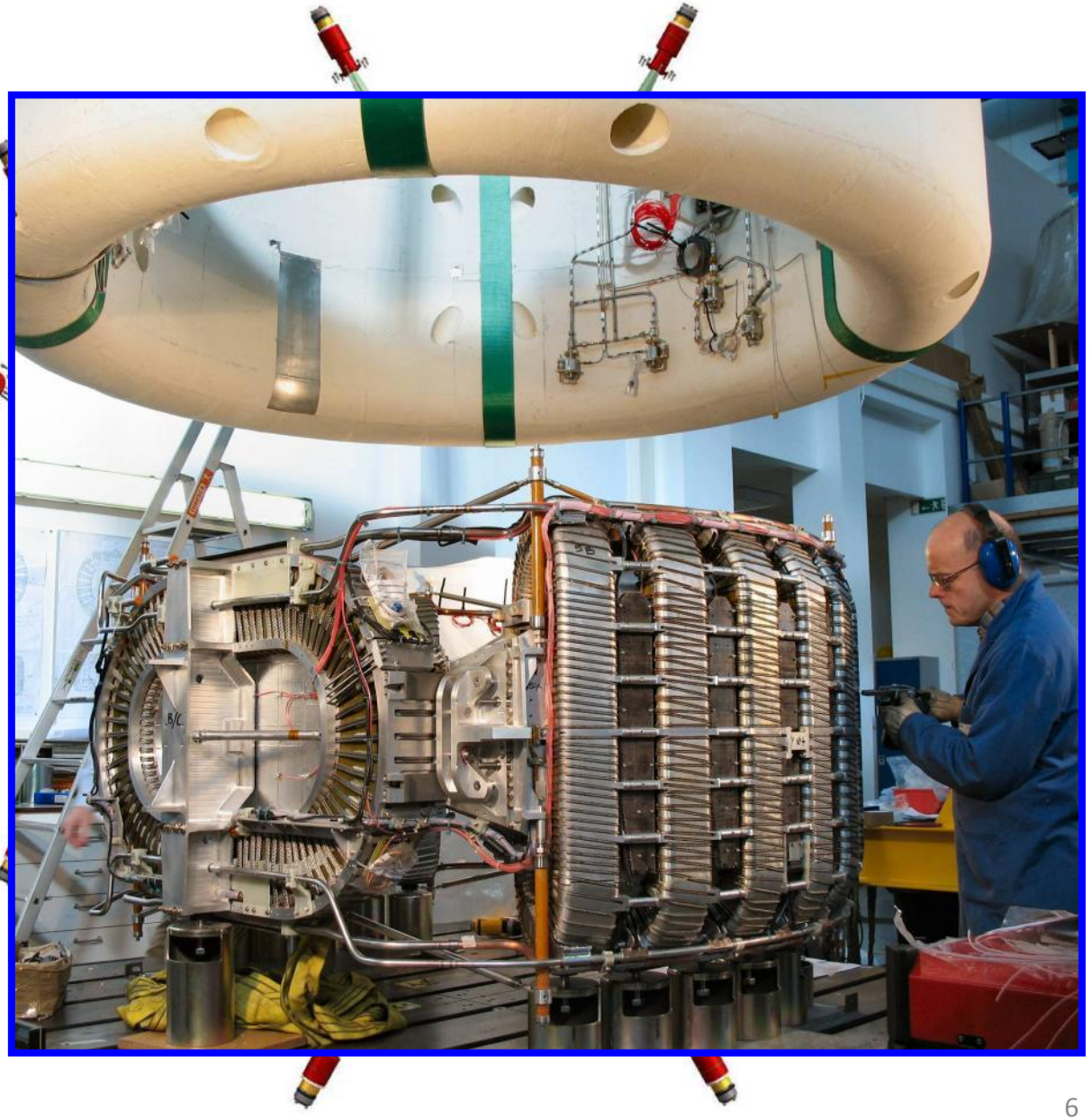


…but was very complicated to fabricate, assemble, and operate.

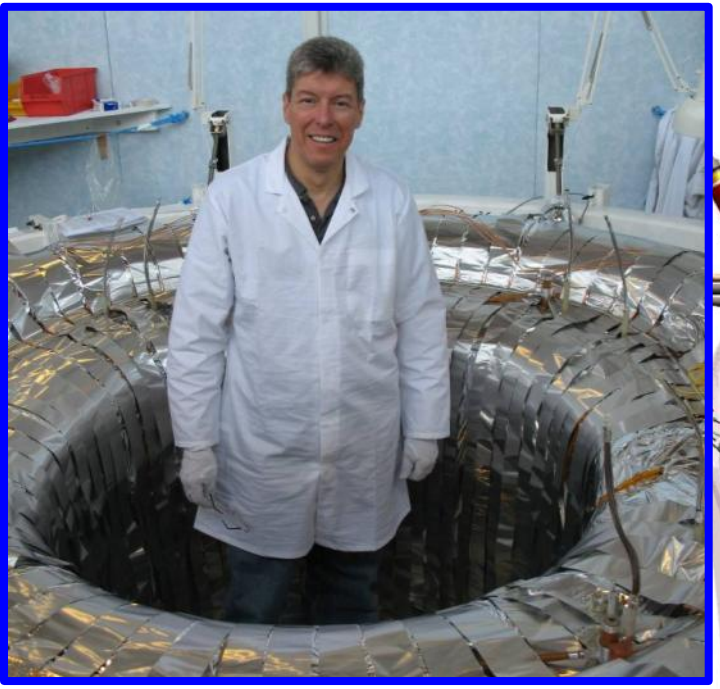
AMS Superconducting Magnet

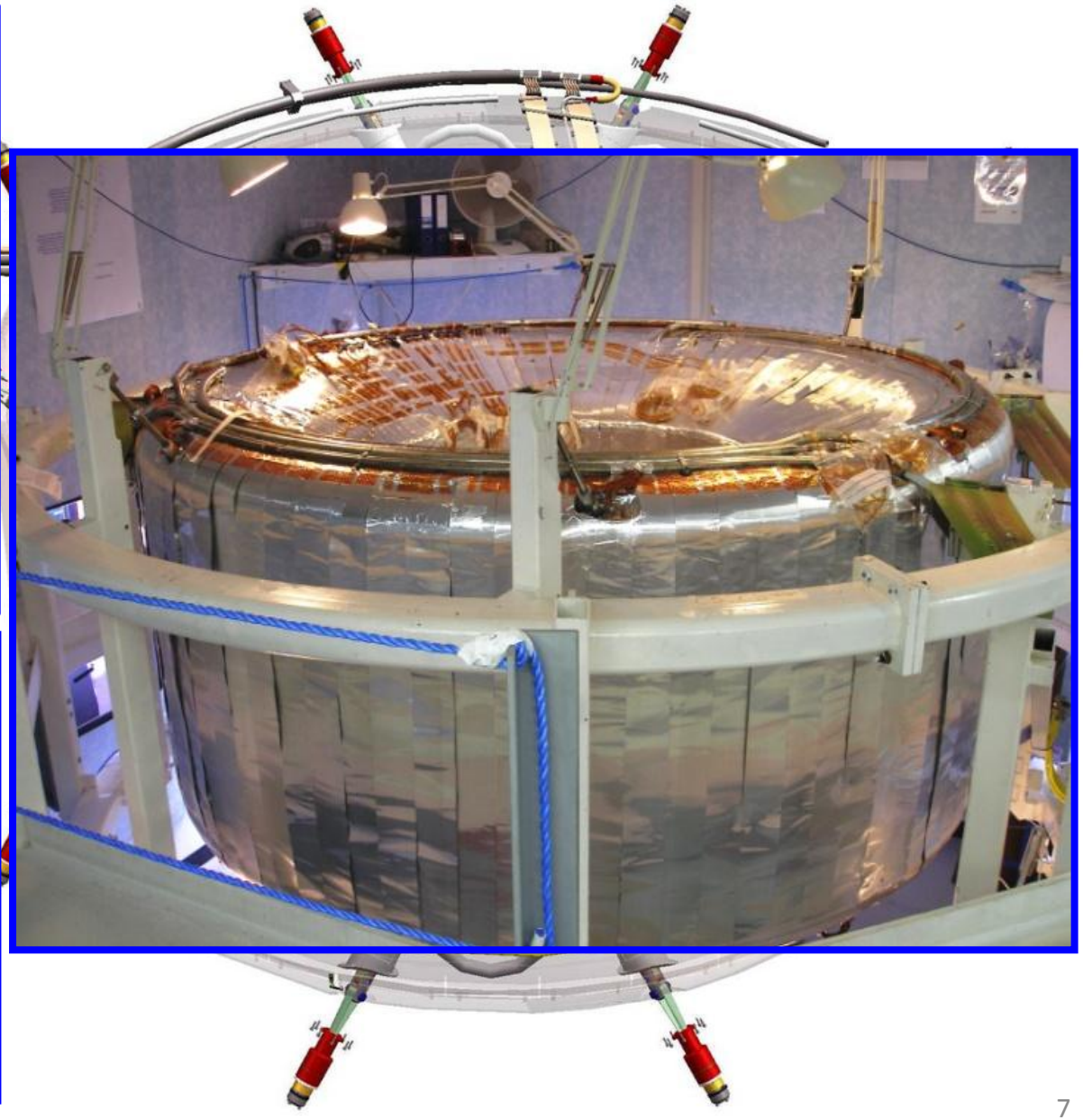
connected to the





AMS Superconducting Magnet





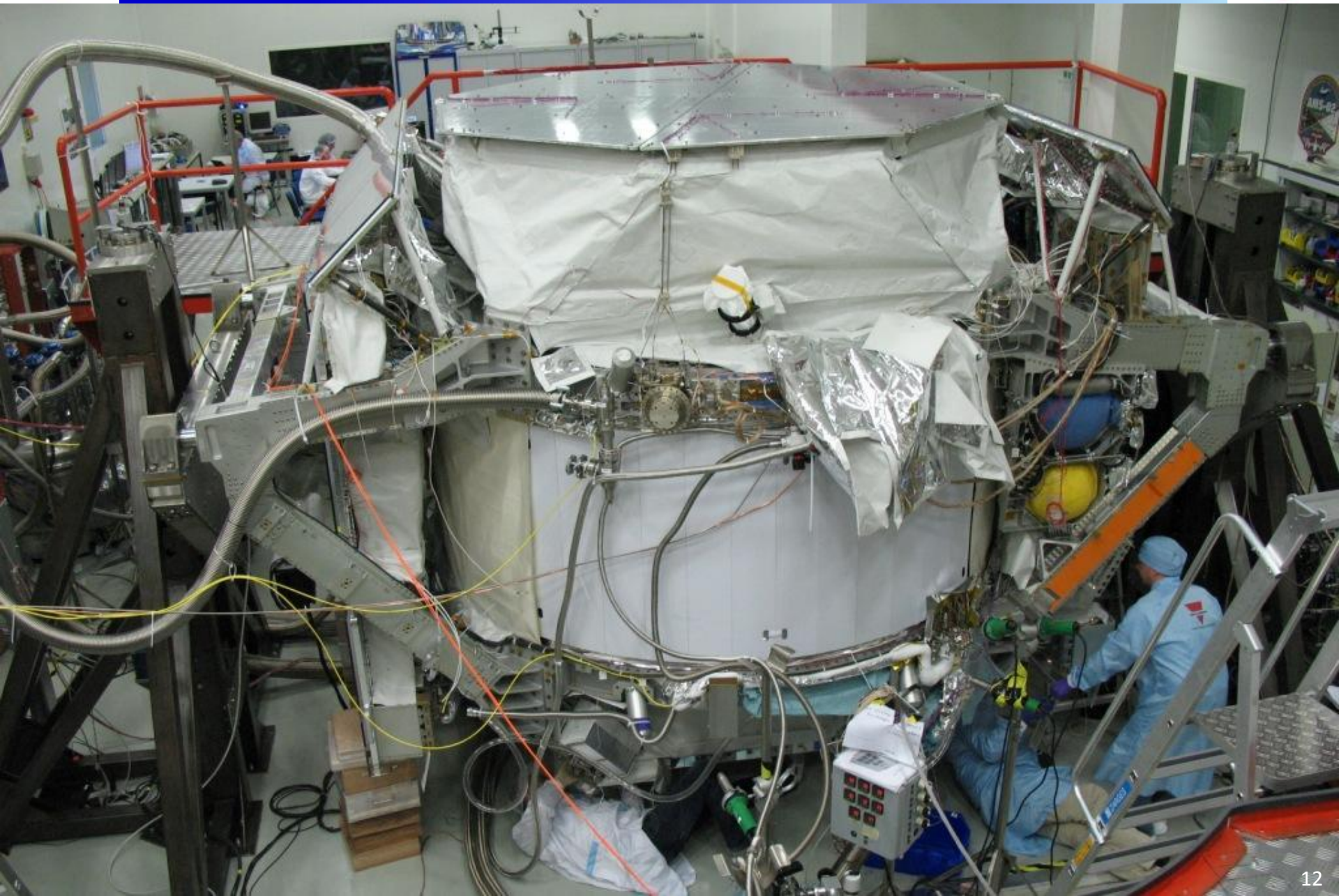
AMS Superconducting Magnet

AMS Superconducting Magnet

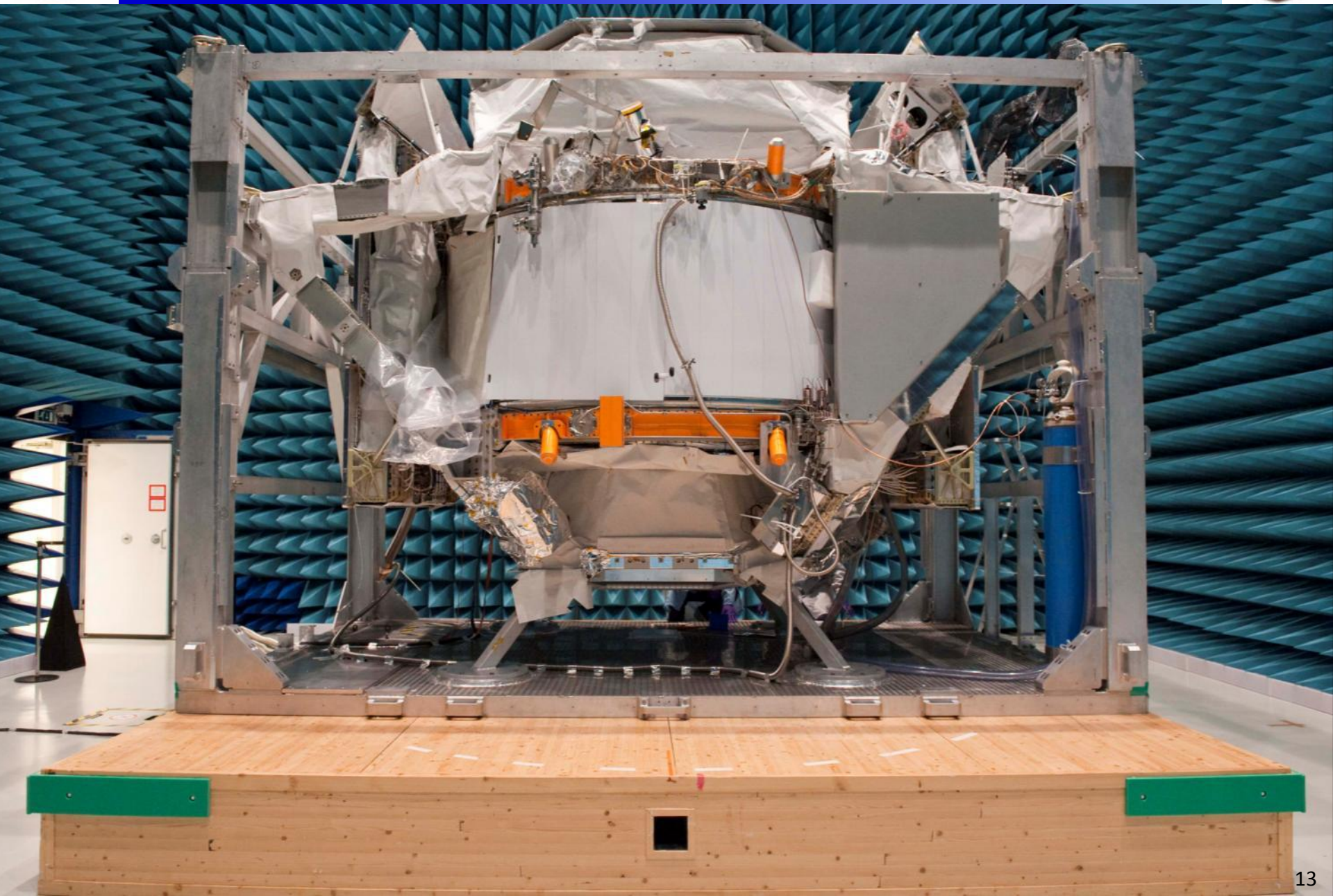
AMS Superconducting Magnet

It was very complicated

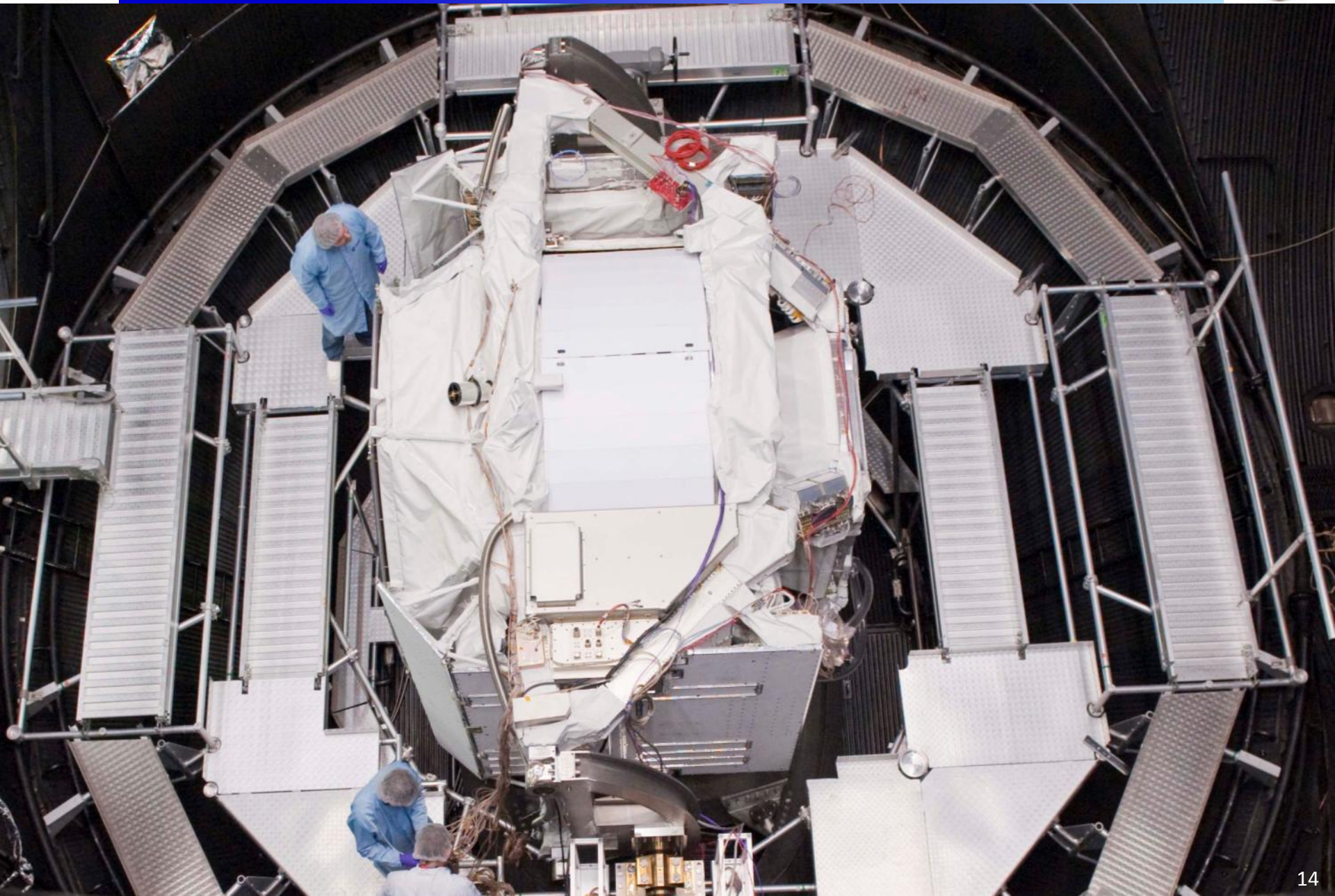
Flight Integration of AMS Detectors with SC Magnet



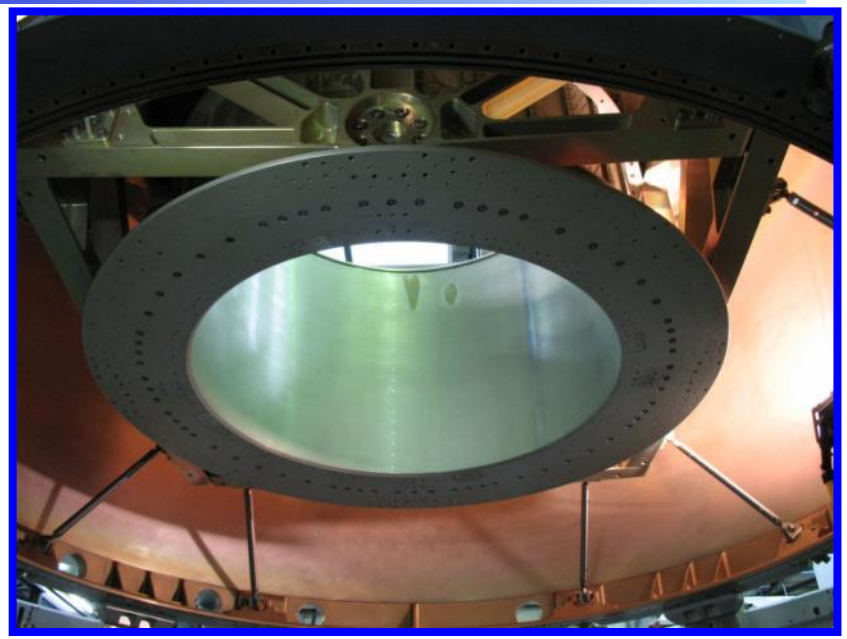
AMS EMI/EMC Test at ESA/ESTEC



AMS Thermal Vacuum Test at ESA/ESTEC

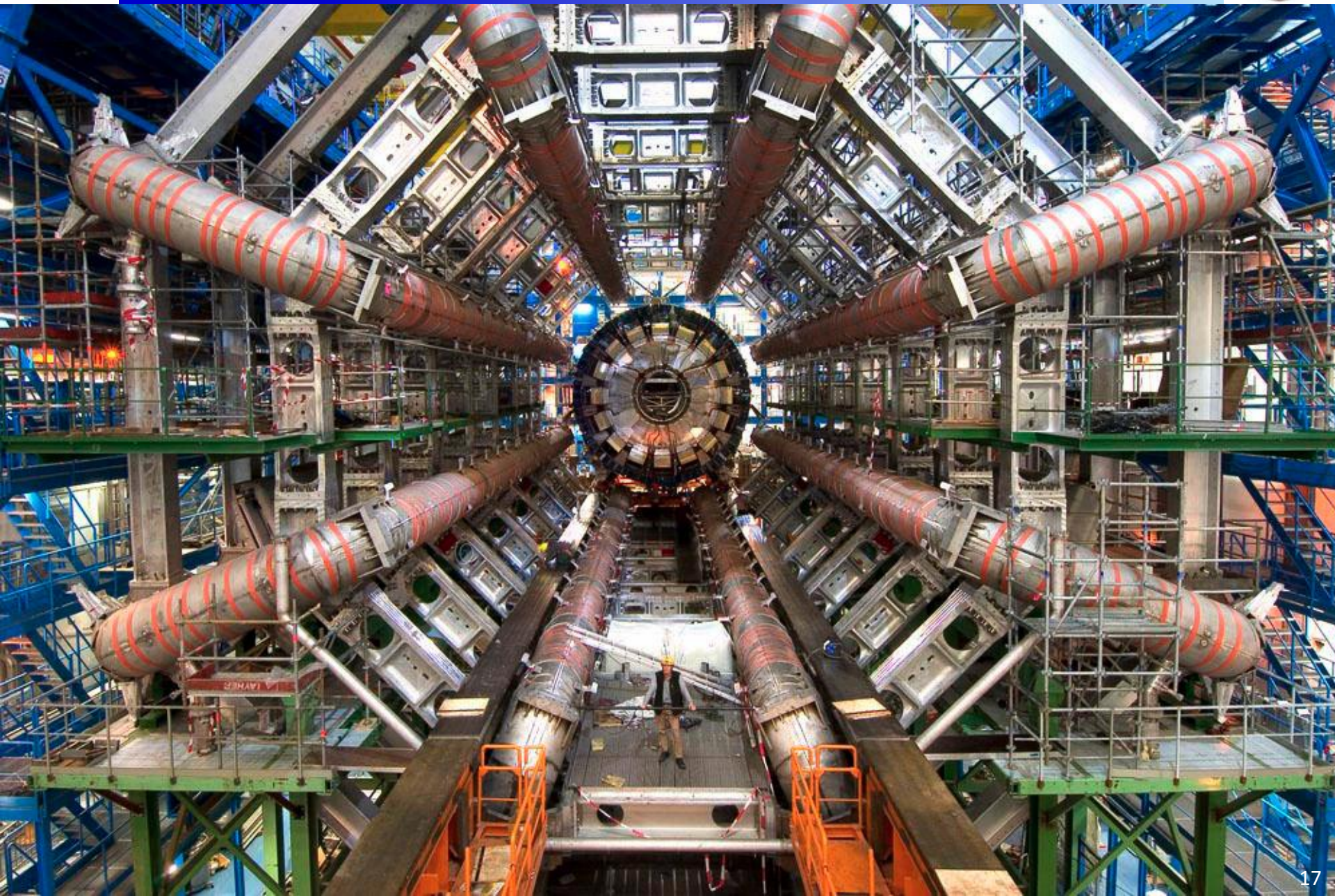


AMS Permanent Magnet Installation



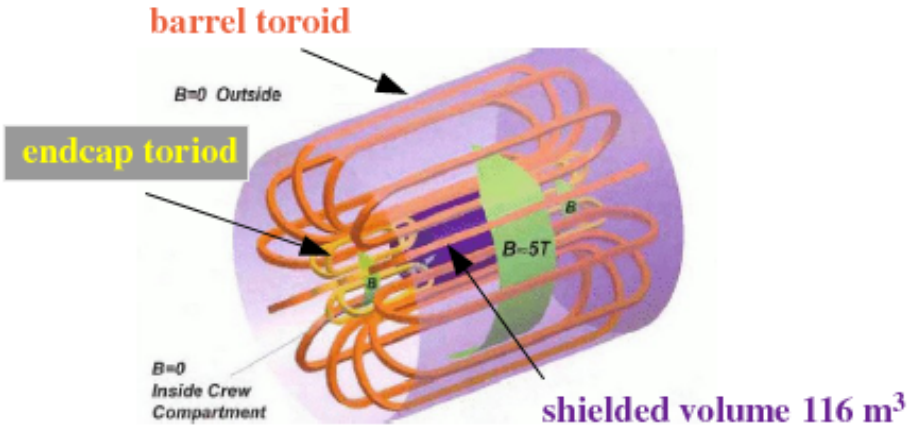

AMS on ISS
AMS-02
ELC2

The ATLAS Superconducting Barrel Toroid at CERN



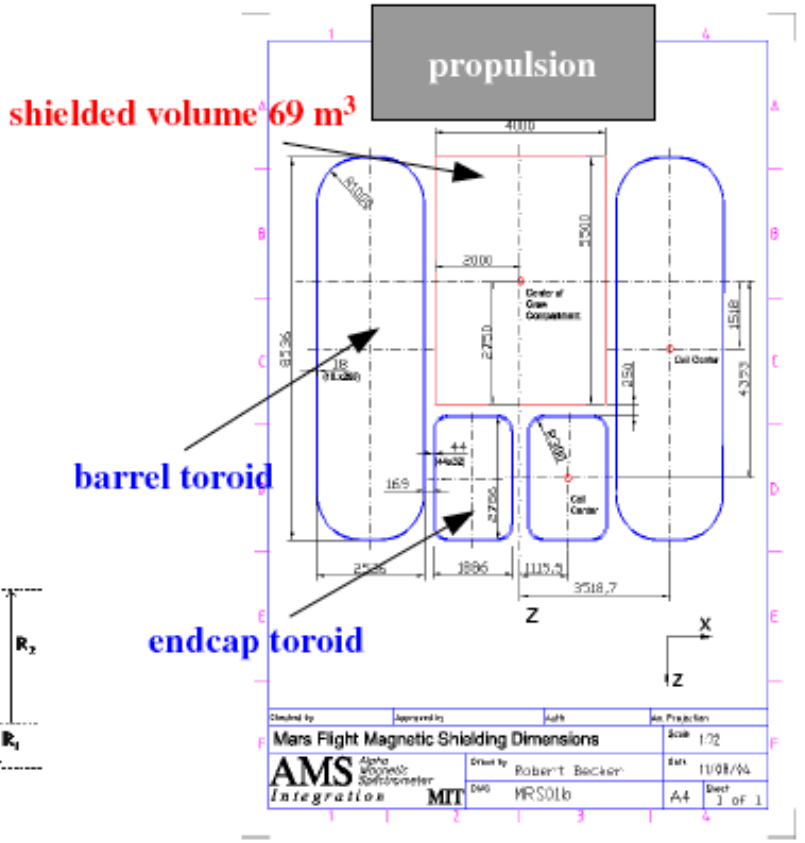
Confined Field Configurations

(1) *J. Hoffman et al., NASA / NIAC Phase 1 Final Report (2005)*



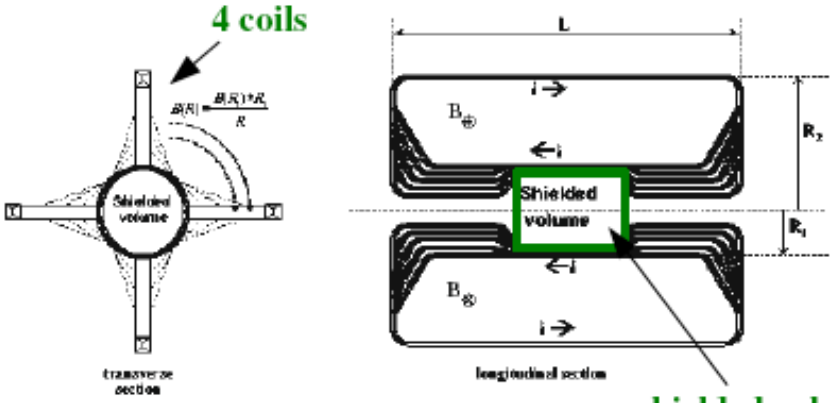
Endcap/Barrel Toroids

(2) *V. Choutko et al., NASA Radiation Shielding Workshop (2004)*



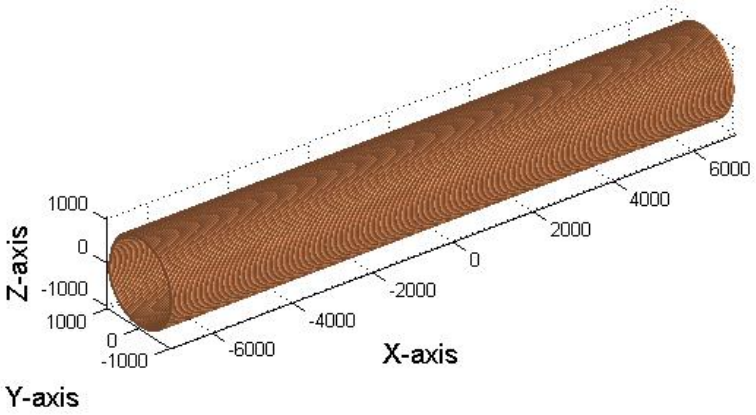
Endcap/Barrel Toroids

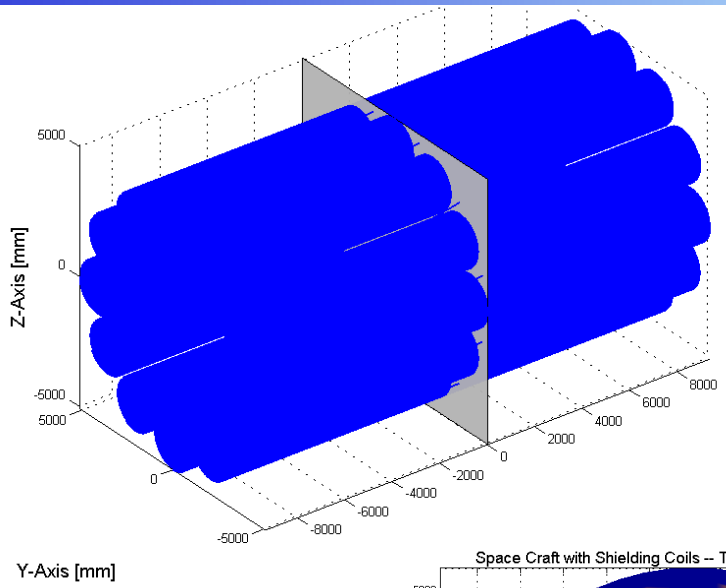
(3) *P. Spillantini, Advances in Space Research 43 (2010) 900*

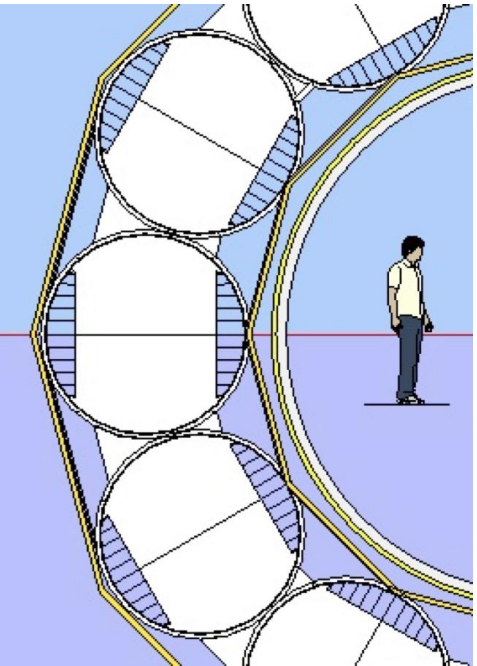


Barrel Toroid

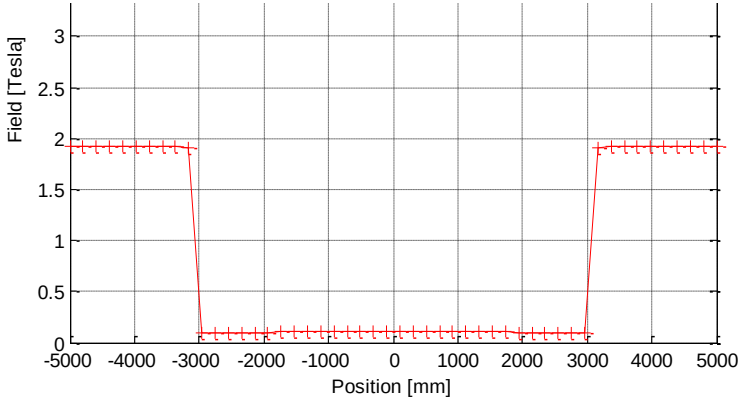
Single Layer Solenoid Coil

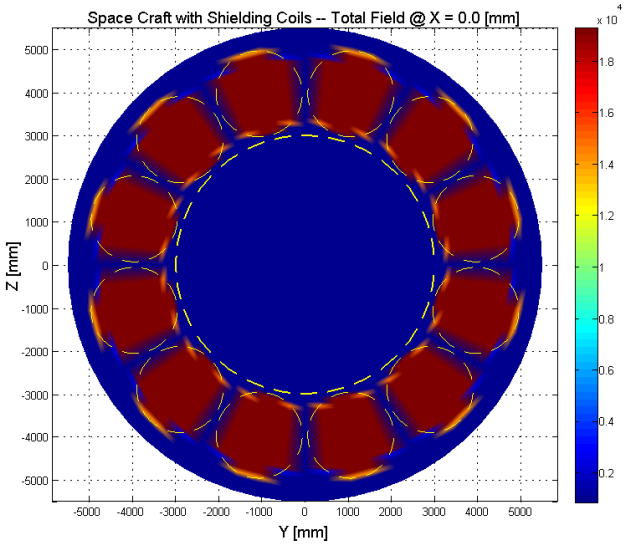






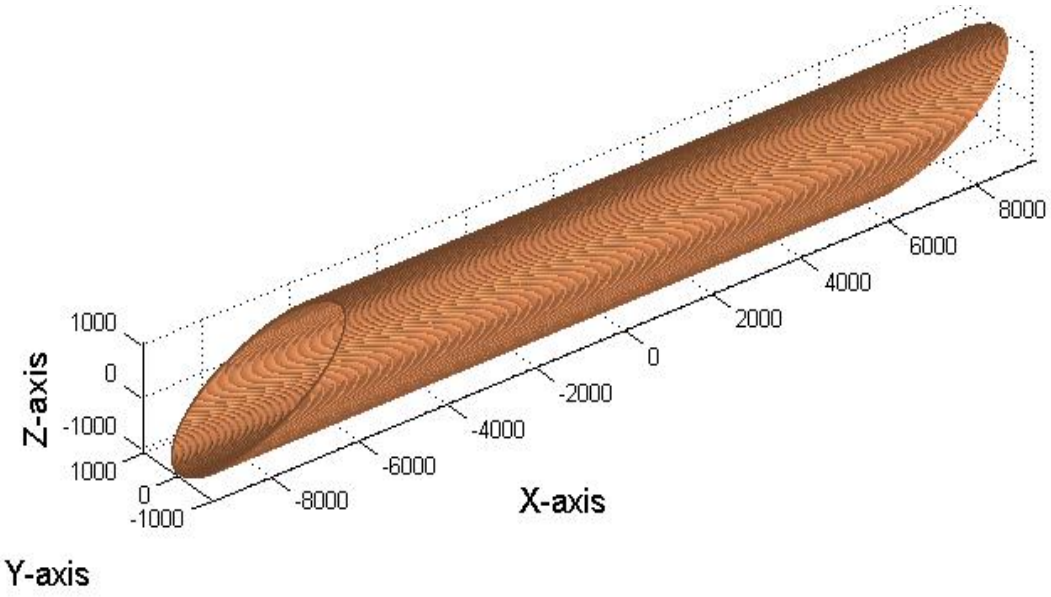
Field inside constant = ~ 0.1 T

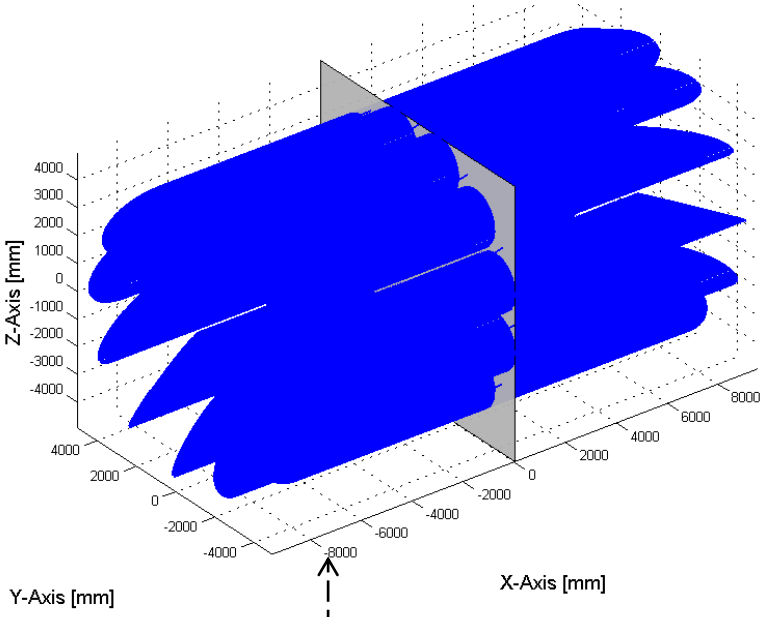


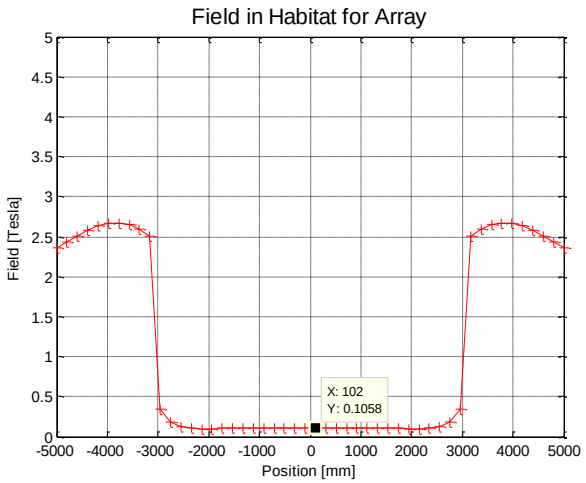


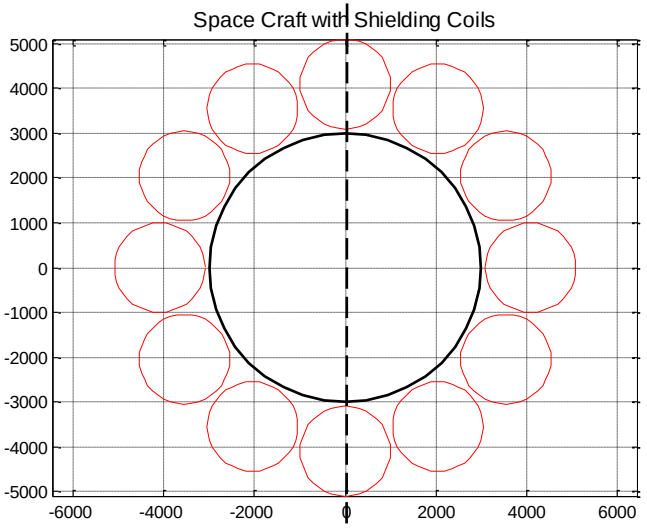
Advanced Magnet Lab

Single Layer Helical Coil









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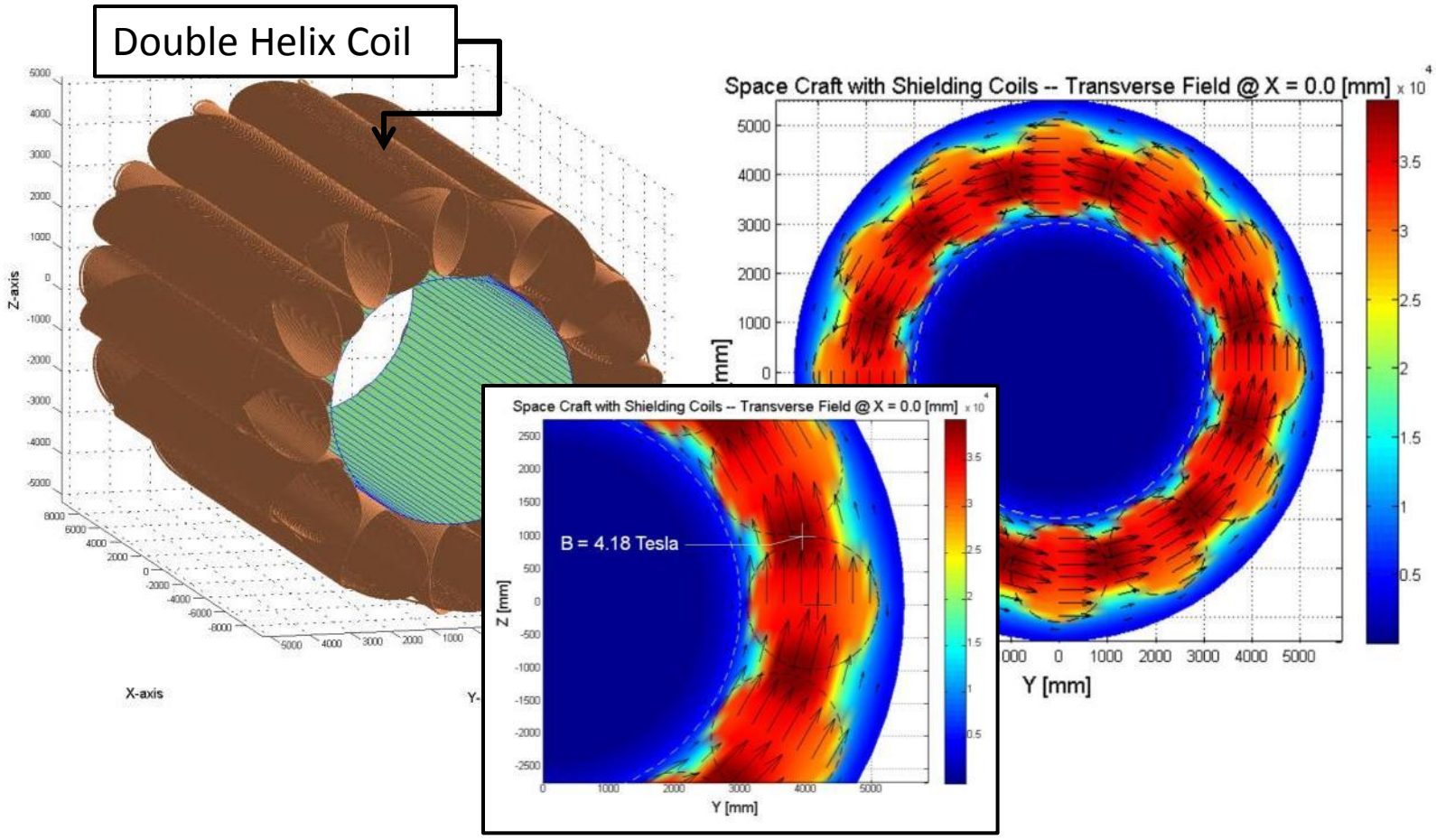
Double Helix Coil

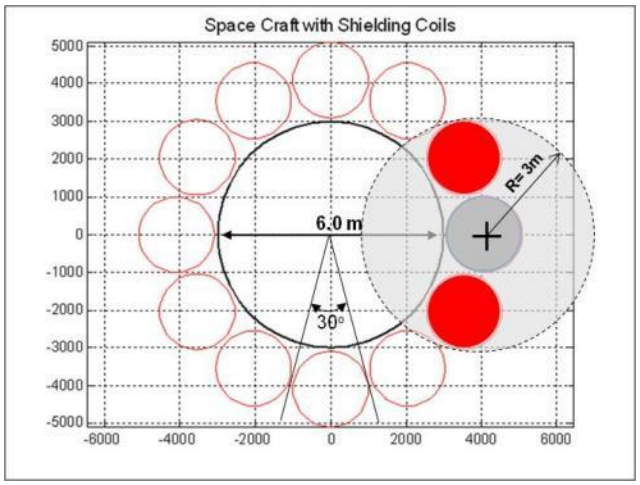


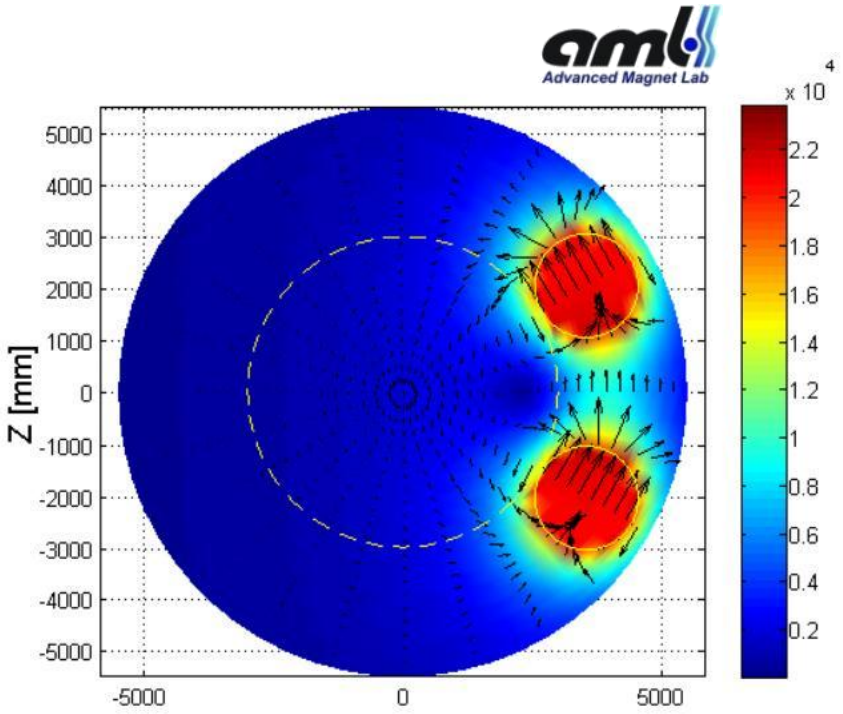
- Field direction changes from coil to coil
- Generating toroidal field with insignificant flux density in spaceship habitat
- Flux sharing between individual coils → strong field enhancement
- Highest field in gap between coils

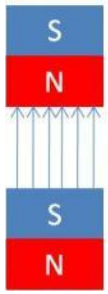
Reference ARSSEM report, ESA: R. Battiston, W.J. Burger, R. Meinke et al (2011)

Forces Acting between Shielding Coils

Effect of Missing Coil:







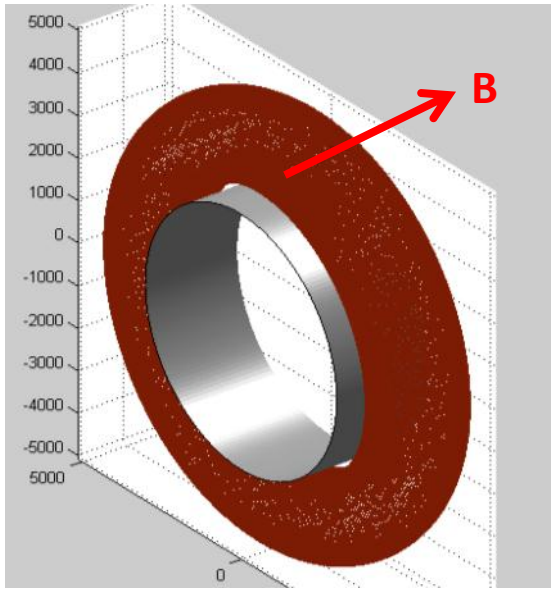
Attractive Force

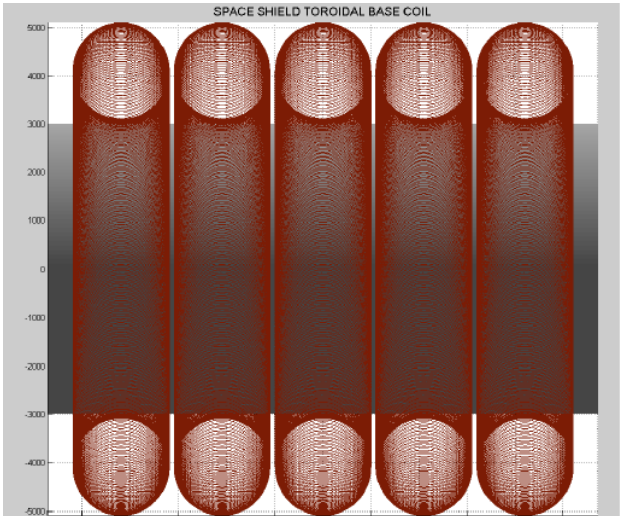
Total acting force between complete coils: ~ 7 MN
Equivalent to weight of 700 tons

Resulting Pressure on spaceship habitat ~ 10 atm

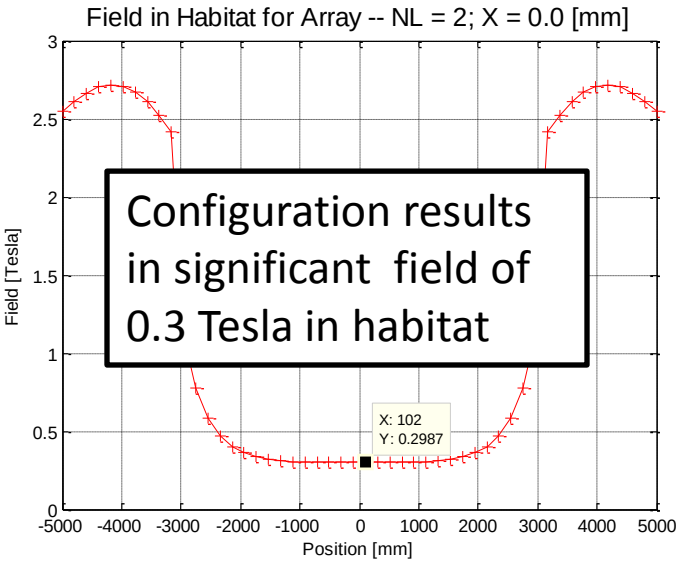
Reference ARSSEM report, ESA: R. Battiston, W.J. Burger, R. Meinke et al (2011)

Double Helix Toroid

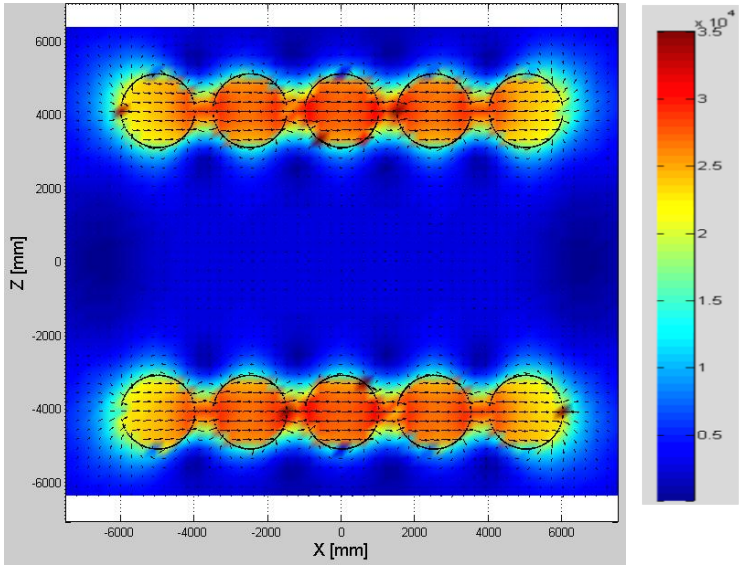




Resulting Field in axial direction of habitat



Configuration results in significant field of 0.3 Tesla in habitat



INFN, University of Perugia/R. Battiston; AML/R. Meinke

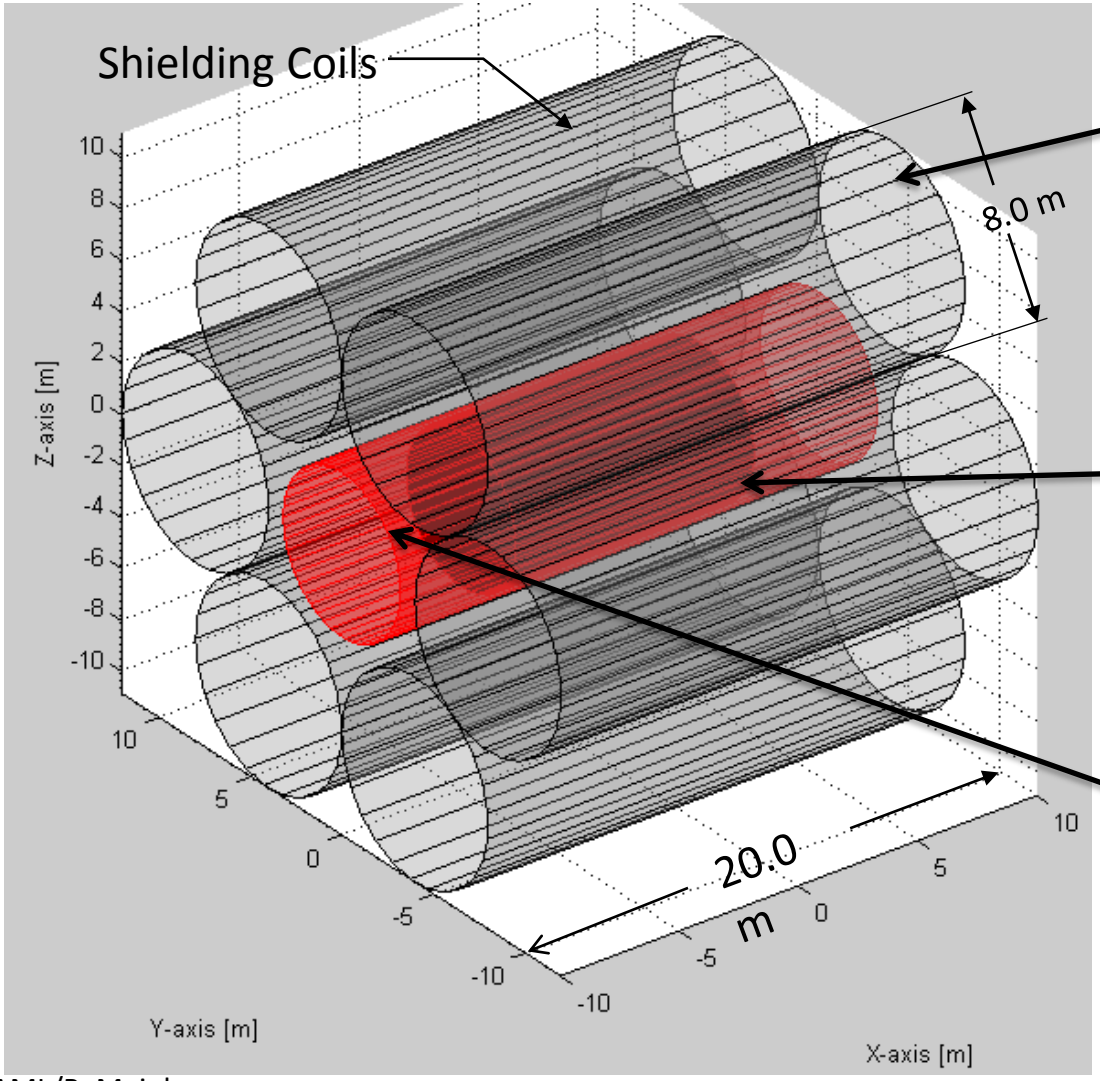
Architectures Summarized

- Straight double-helix coil array produces an insignificant field within the Habitat, but large forces acting between coils and on Habitat
- Toroidal coils resulted in low forces on Habitat but has larger fields within Habitat
- A scalable solution is needed with a low magnetic field that is extensible: 6+1 Solenoidal (non-toroidal) Coil System
  - Since structural mass increases exponentially with magnitude of the B-field a smaller field size and larger field extent is considered

6+1 Solenoidal Coil System

The following 6+1 Solenoidal Coil System is a only a potential concept. It requires *considerably* more design, research & development, operational analysis, and safety analysis.

Shielding Coils & Habitat with Compensation Coil



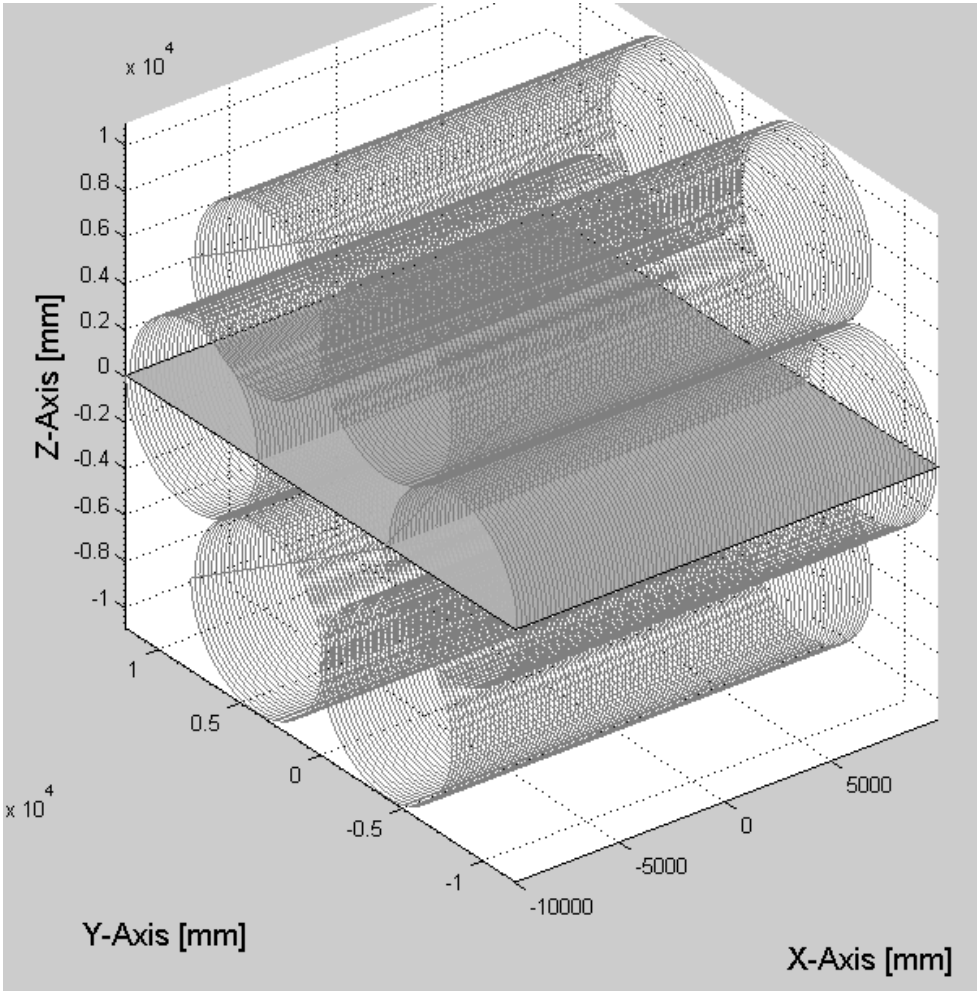
6 shielding coils of 8 meter dia.

6 meter dia. Habitat

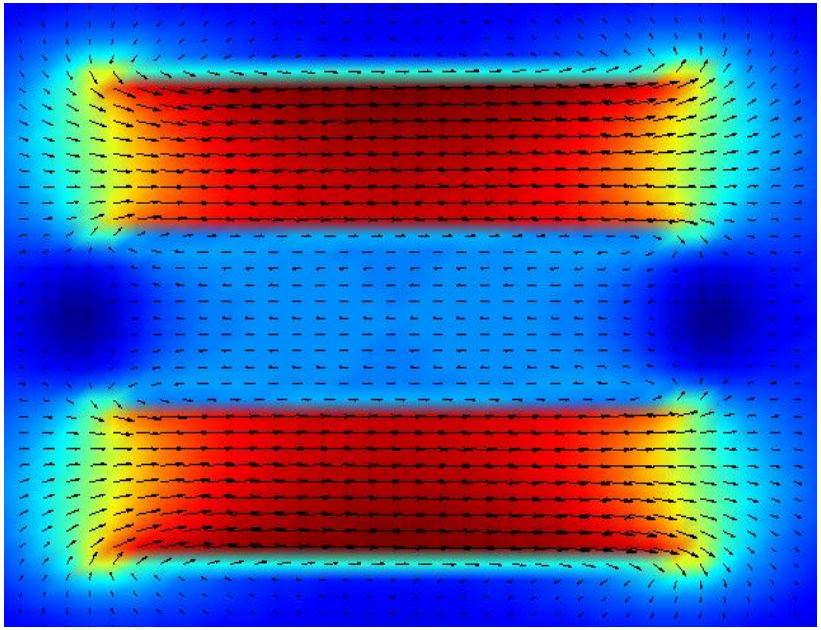
Compensation Coil

AML/R. Meinke

Field in X-Y-Plane

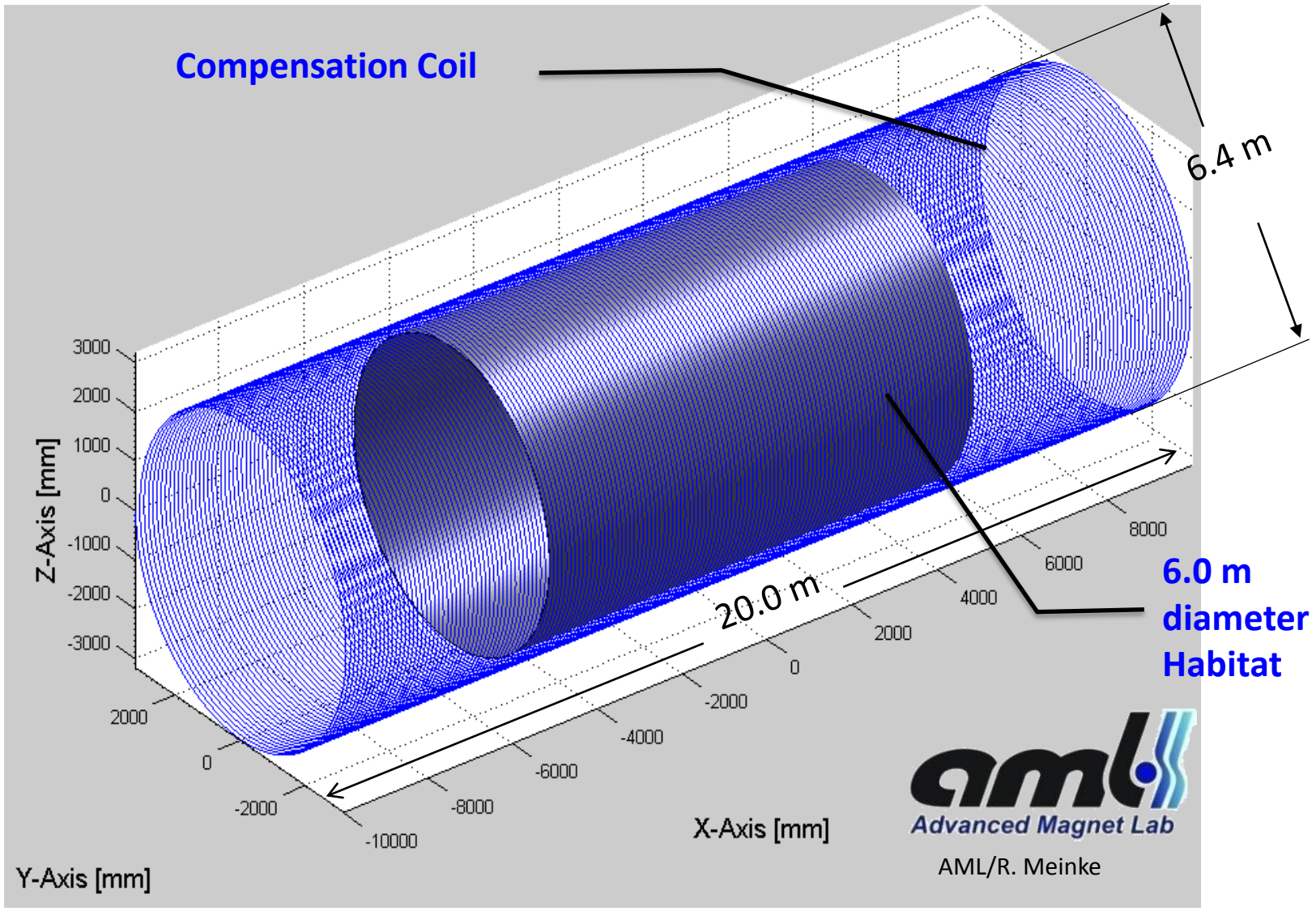


Field in X-Y-Plane



AML/R. Meinke

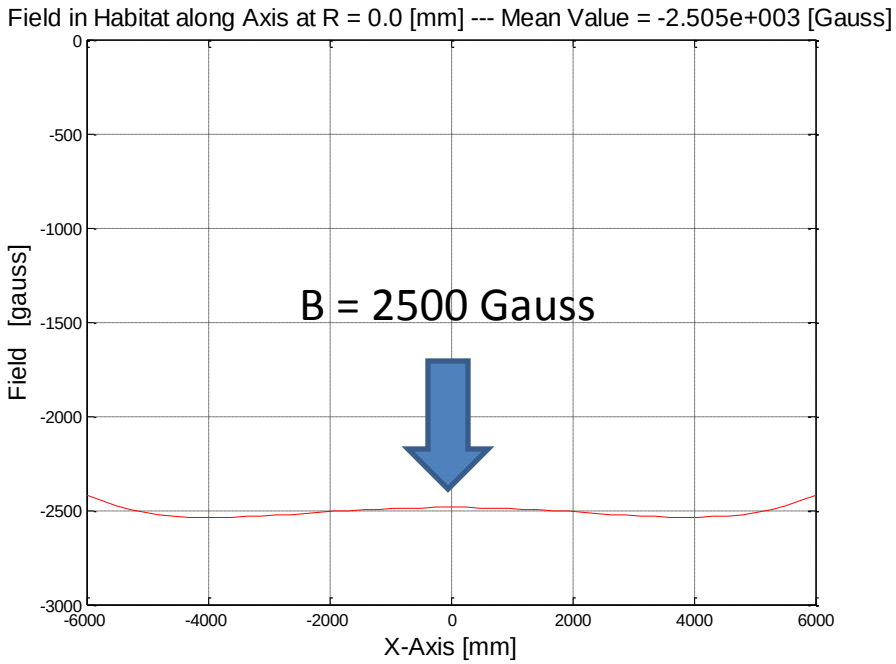
Central Compensation Coil



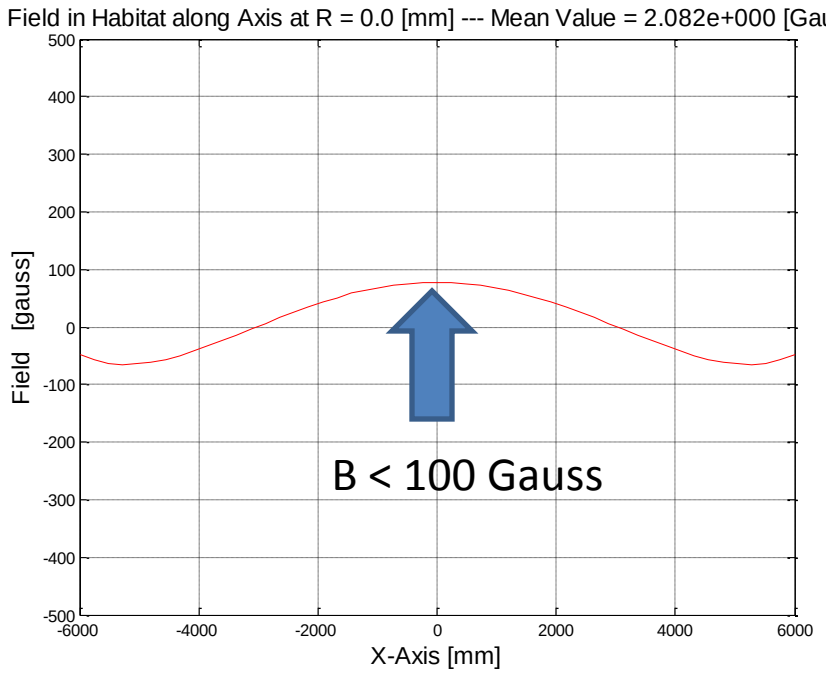
Effect of Compensation Coil (Not Optimized)

Field in Habitat…

…without Compensation Coil



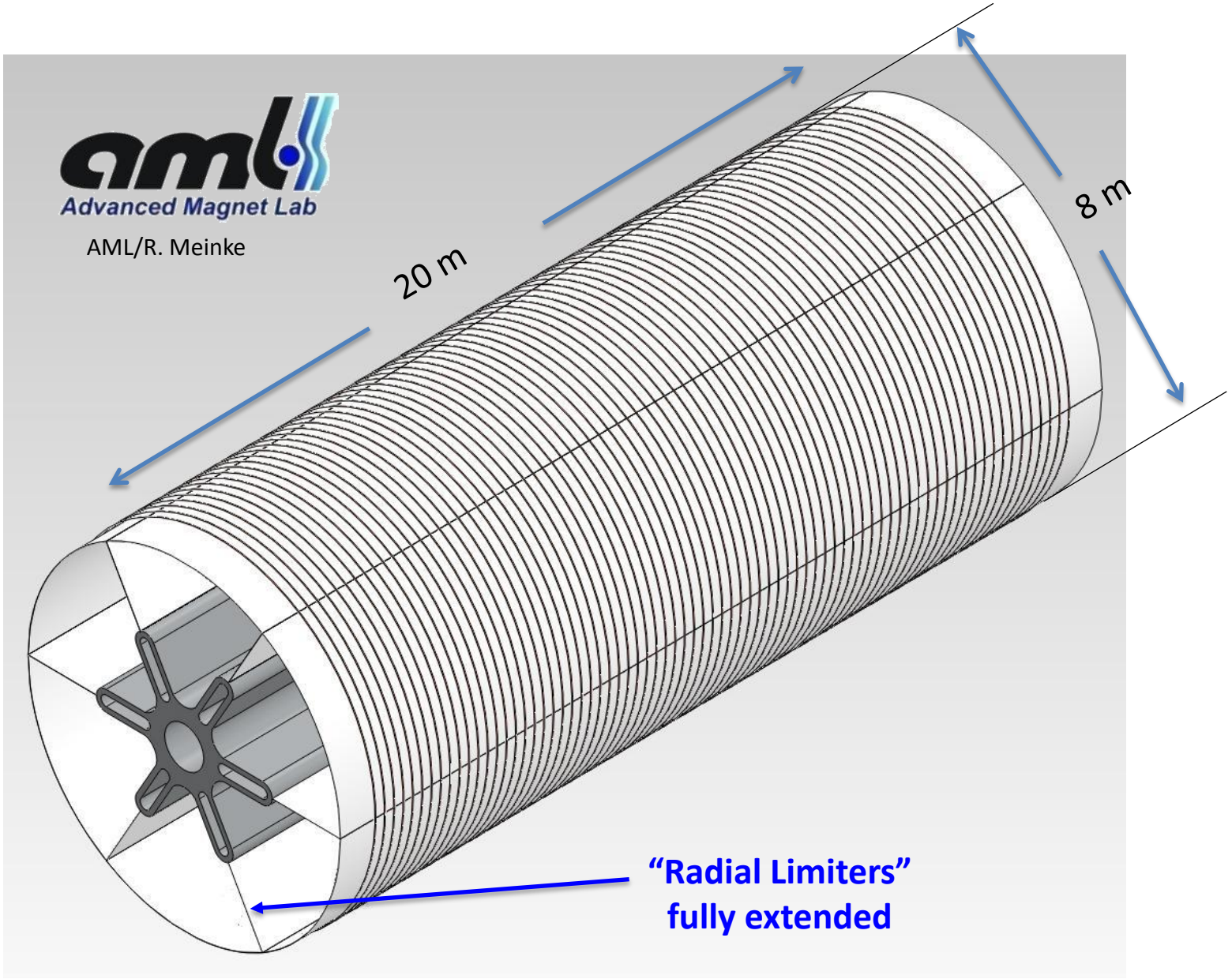
… with Compensation Coil



High magnetic fields can be harmful to humans as well as electronics and must be reduced

Compensation can bring field to near zero Gauss with optimization

Large Fully Expanded Coil

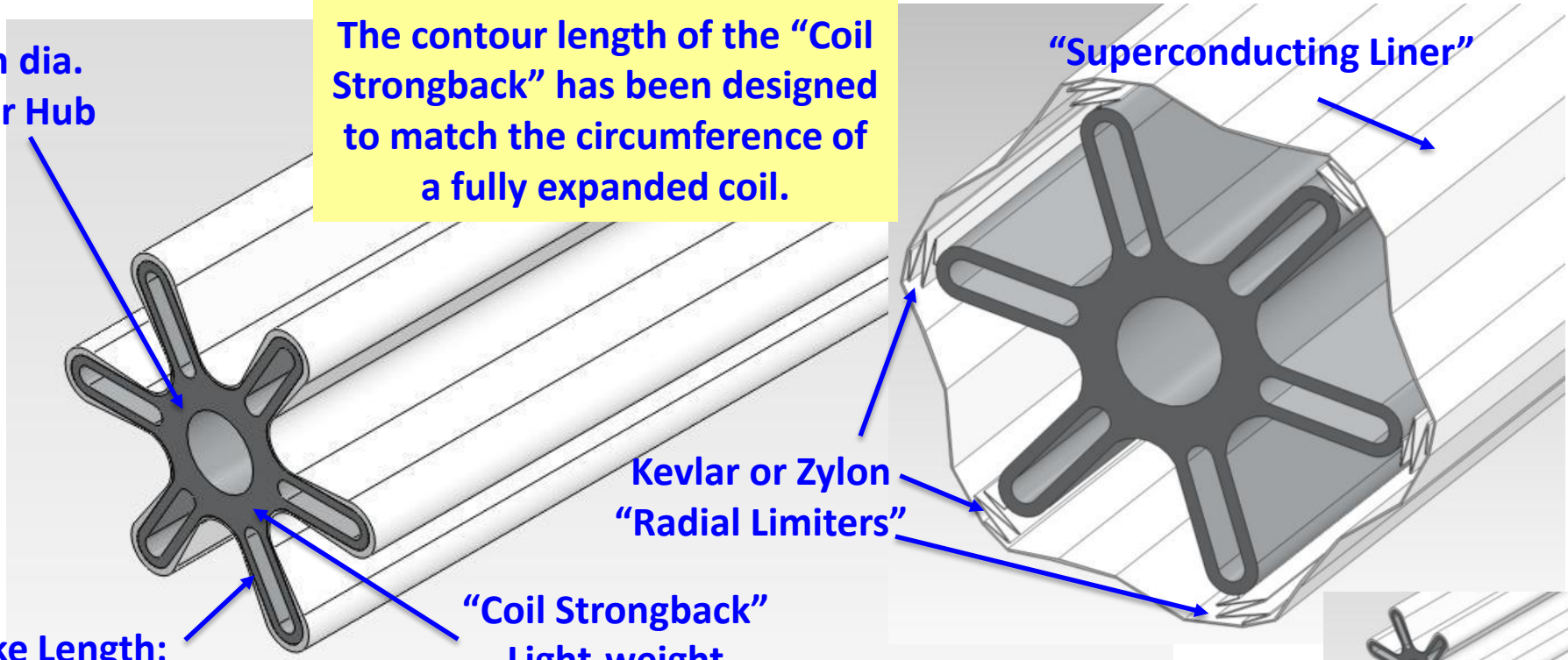


Solenoid Coil Fully Contracted/Partially Expanded

~1 m dia.
Inner Hub

The contour length of the "Coil Strongback" has been designed to match the circumference of a fully expanded coil.

"Superconducting Liner"

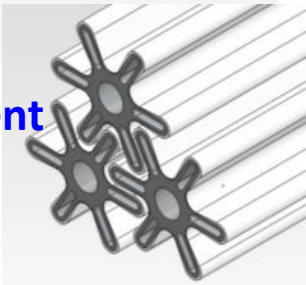


Kevlar or Zylon
"Radial Limiters"

Spoke Length:
~1 m

"Coil Strongback"
Light-weight
composite structure

This shape allows efficient packing for launch

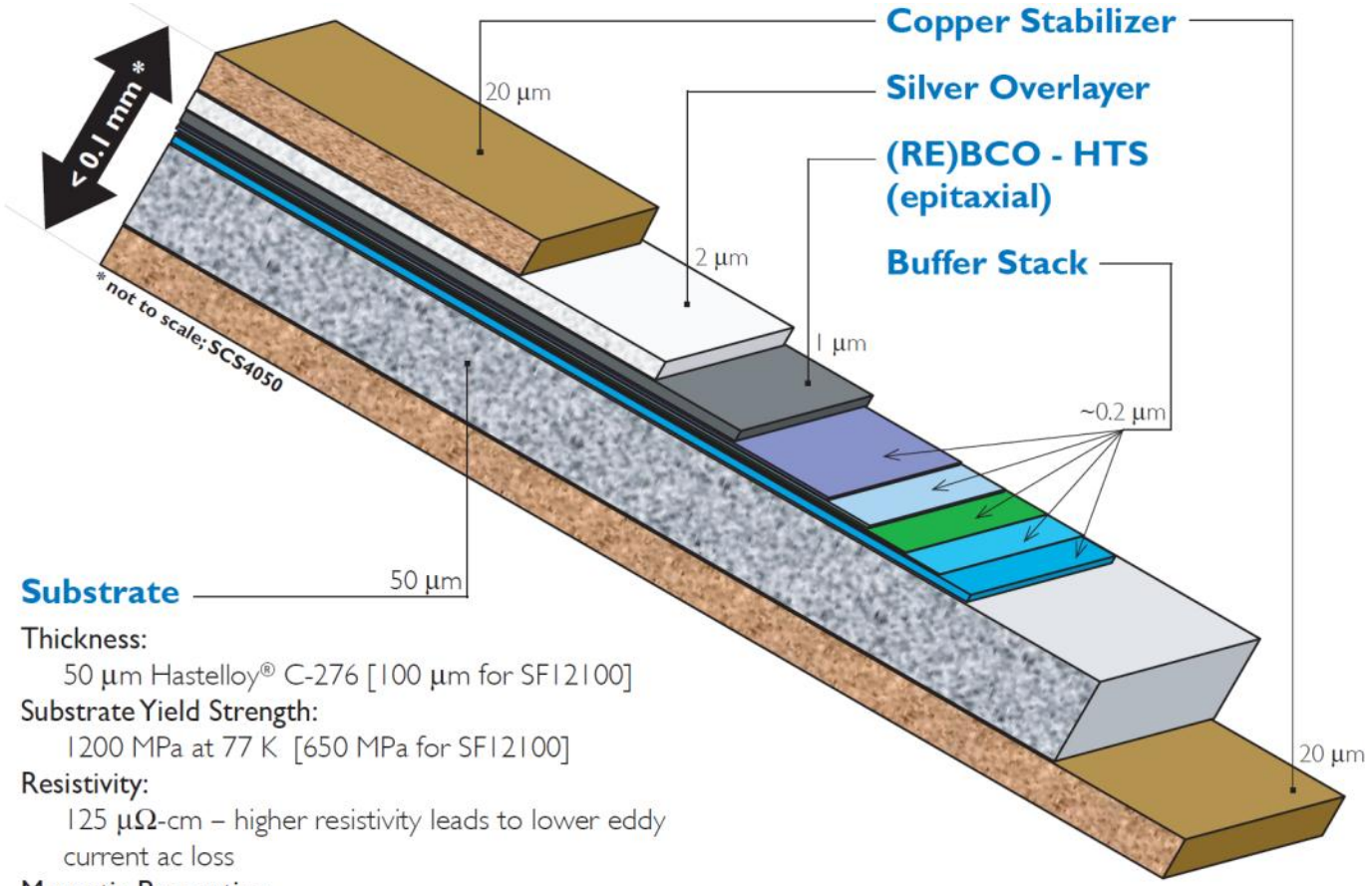


Advanced Magnet Lab

AML/R. Meinke

The "Superconducting Liner" is comprised of 40-50 mm wide by 0.10-0.23 mm thick superconducting tape sandwiched between 2 layers of stitched fiber mats made from Kevlar or Zylon. Zylon, with a tensile strength of about 5.4 GPa, is cryogenically qualified. The fiber material is available with a metal coating to improve thermal conductivity. Under the effect of magnetic pressure (Lorentz forces) the coil will expand.

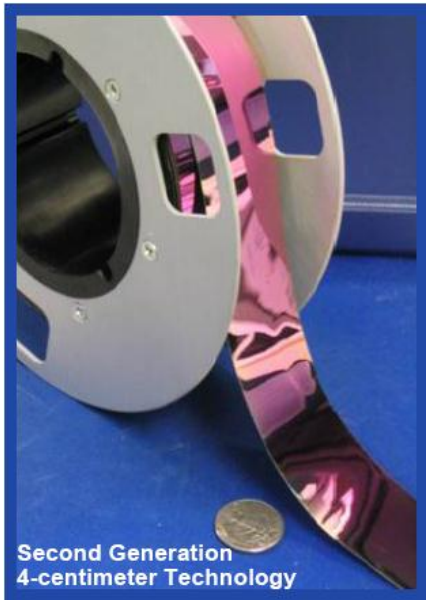
High Temperature Superconducting Tapes



Substrate

Thickness:
50 µm Hastelloy® C-276 [100 µm for SF12100]
Substrate Yield Strength:
1200 MPa at 77 K [650 MPa for SF12100]
Resistivity:
125 µΩ-cm – higher resistivity leads to lower eddy current ac loss
Magnetic Properties:
non-magnetic, leads to lower ferromagnetic ac loss

SuperPower Inc.



Tape thickness: 0.21- 0.23 mm

amsc

REBCO, "Rare Earth" elements with Barium Copper Oxide. RE elements include the following metals: Europium (CAS 15522-71-1), Dysprosium (CAS 15522-69-7), and Gadolinium (CAS 14768-15-1), Yttrium (7440-65-5), Samarium (7440-19-9)

SuperPower High Temperature Superconductor

Electropolishing of Hastelloy substrate

Each station is a batch process using ~1500m spools with the ability to increase lengths

Each Vacuum Deposition chamber does 1-3 spools at a time with different materials, feed rates, temperatures, and pressures

Visual inspection

Current testing

SuperPower High Temperature Superconductor

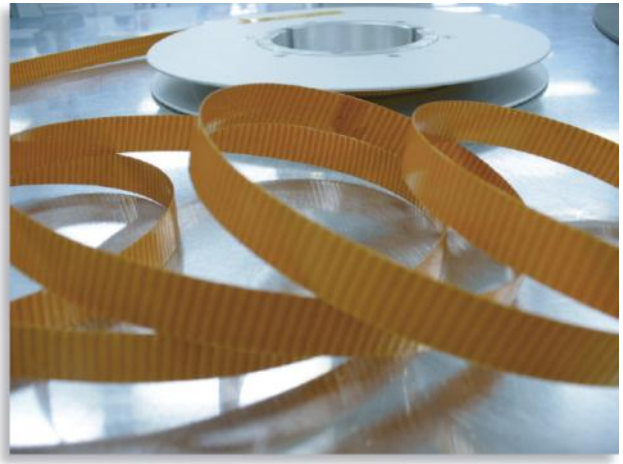
SuperPower® 2G HTS Wire Specifications

Second-Generation High Temperature Superconductor (2G HTS)

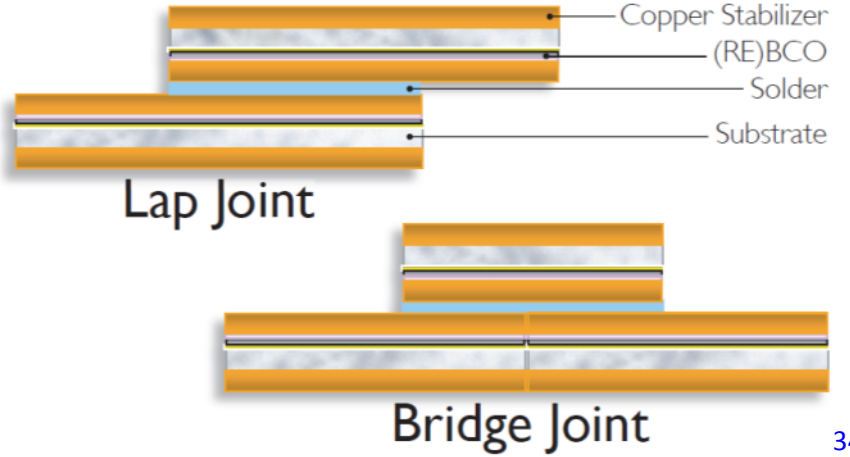
SuperPower has been developing (RE)BCO-based 2G HTS wire at its manufacturing plant in Schenectady, NY since 2000 and is now routinely producing long lengths of high performance wire that is being shipped to customers around the world for a wide range of applications.

Within the 1500 m spools, a typical length without a "dropout" (a defect that interrupts superconductivity) is currently 100-300 m. To produce longer lengths, the tape must be spliced as shown below.

3-5 years ago, the maximum defect-free length was only 10s of meters and the yield per spool was on the order of ~10%. The yield is currently ~74% and steadily improving as continuous inspection methods are developed and more process controls are implemented.

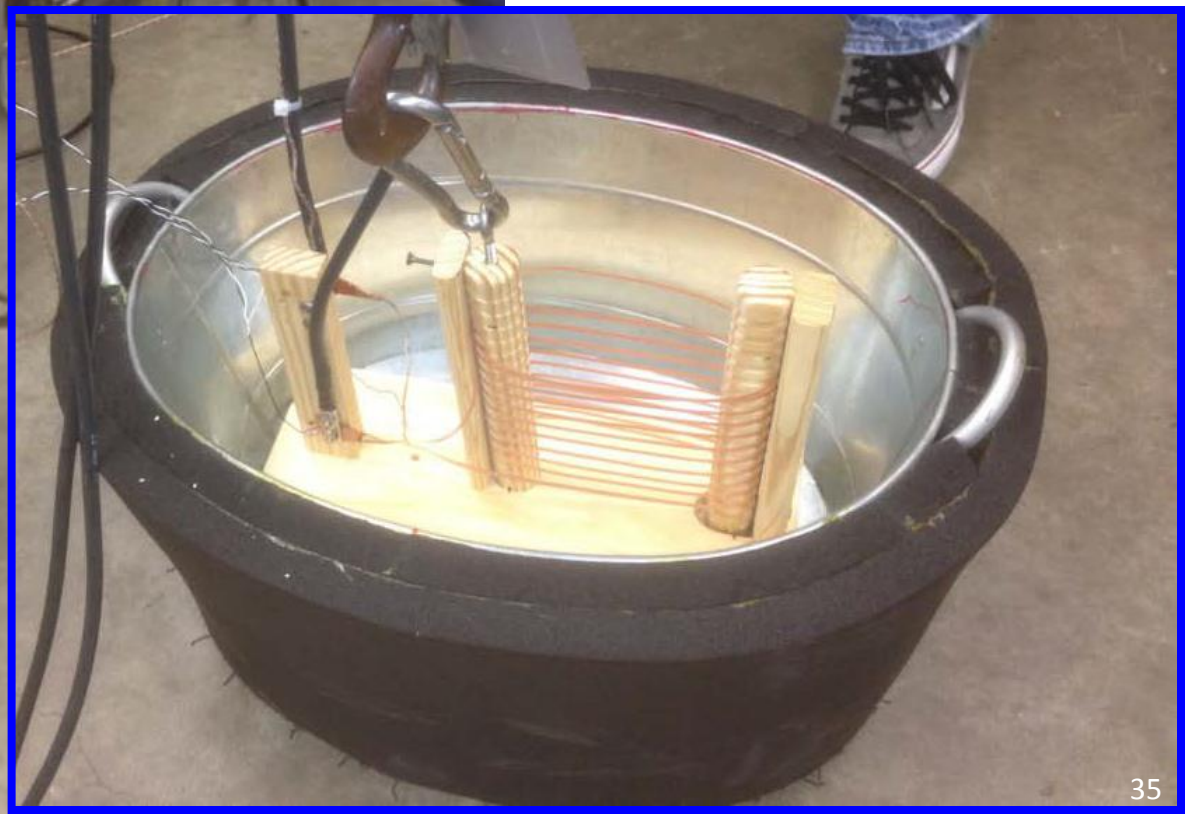


Kapton insulated HTS

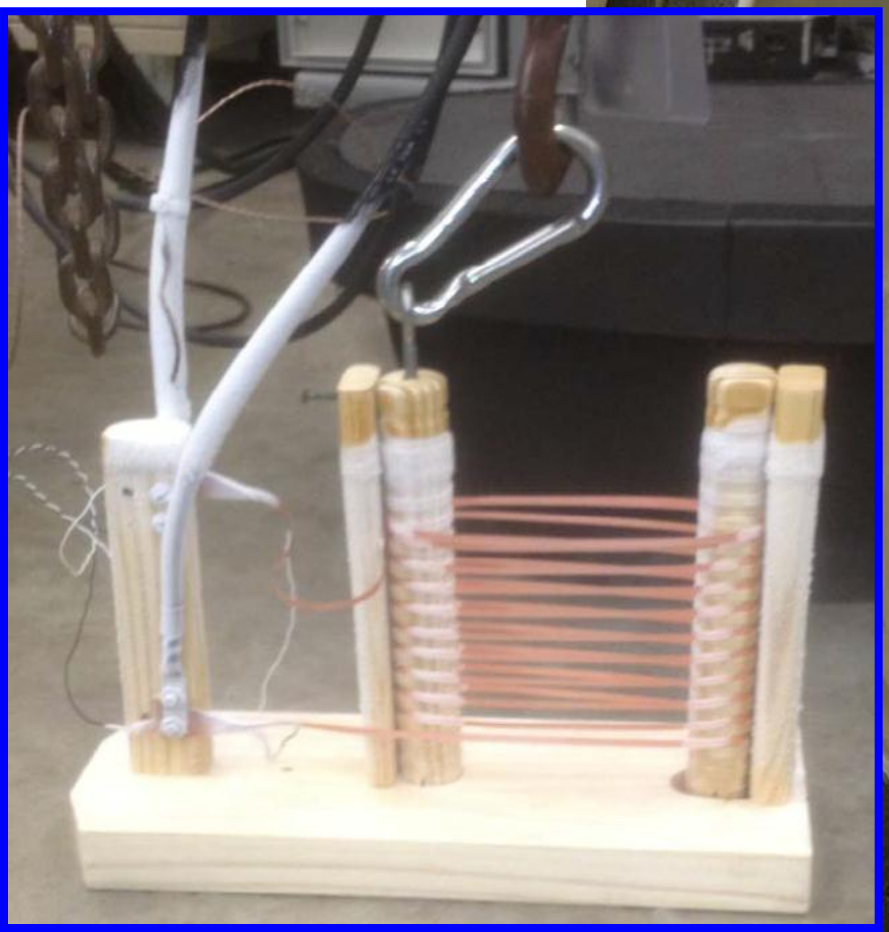


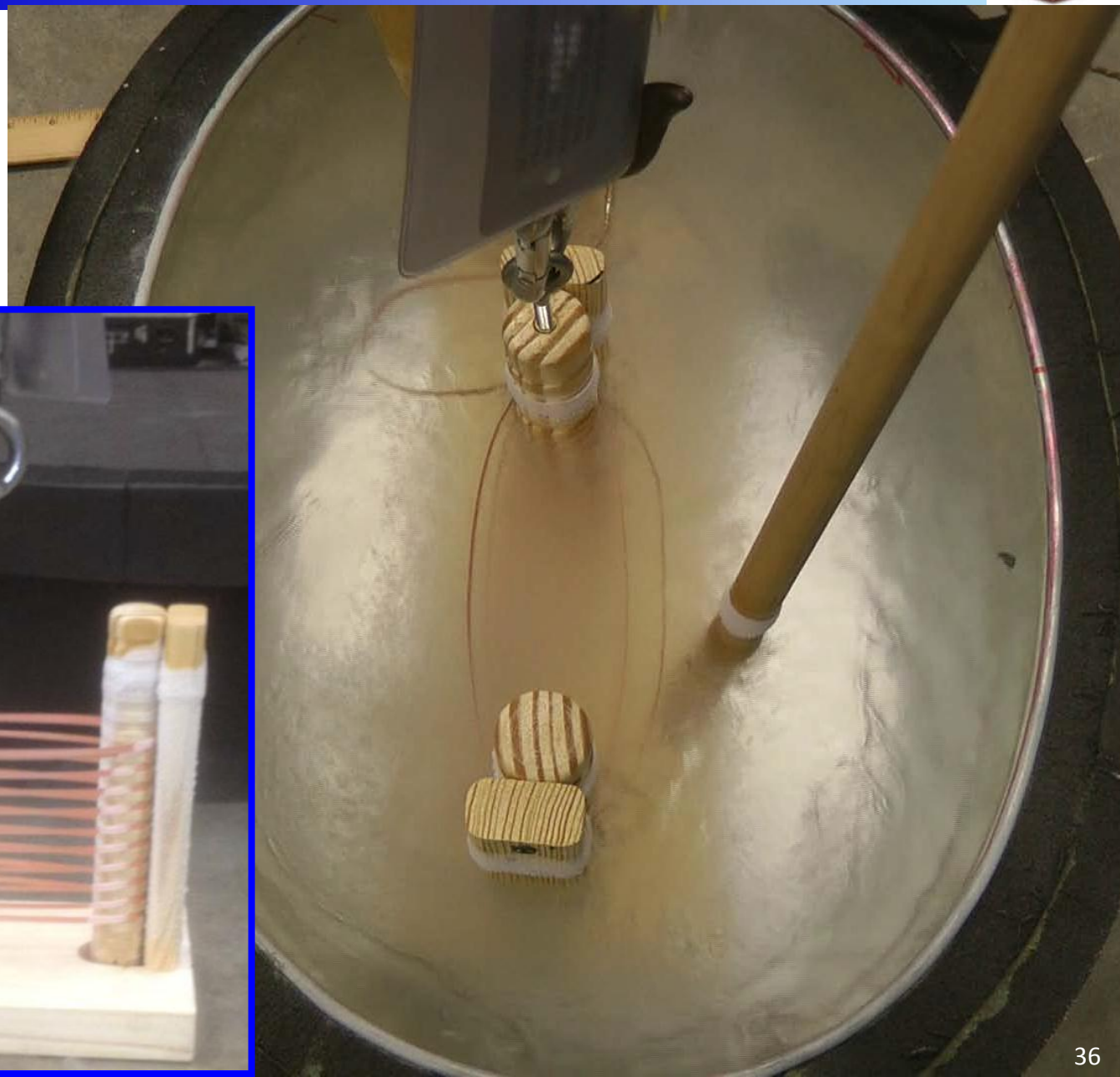
SuperPower Inc.

Crude test with 4 mm wide superconducting tape submerged in liquid nitrogen and run at 100 amps

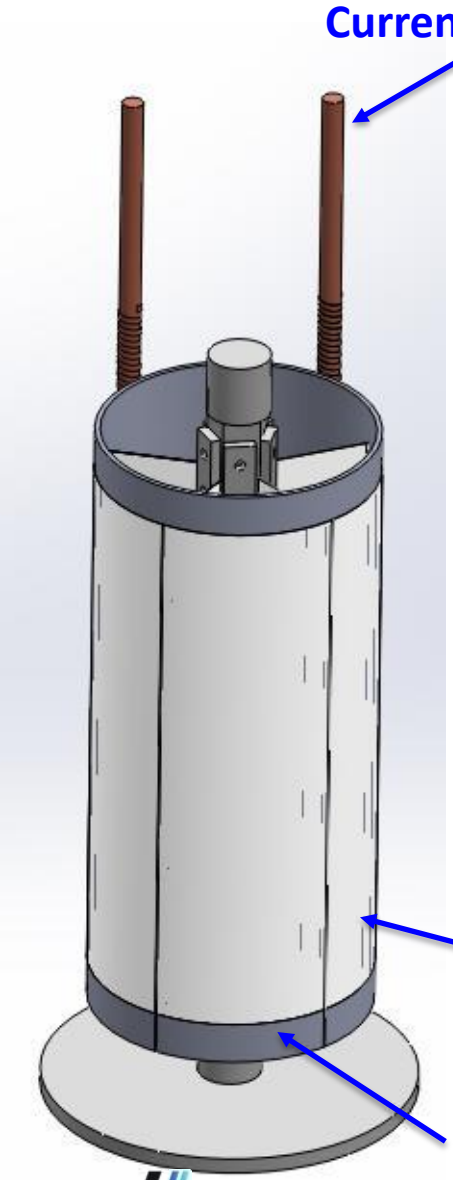


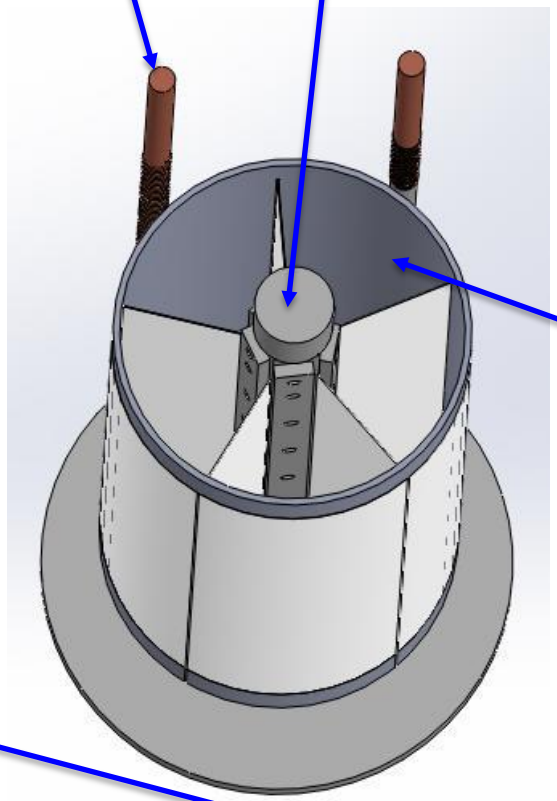
Moving the tape at 100 amps

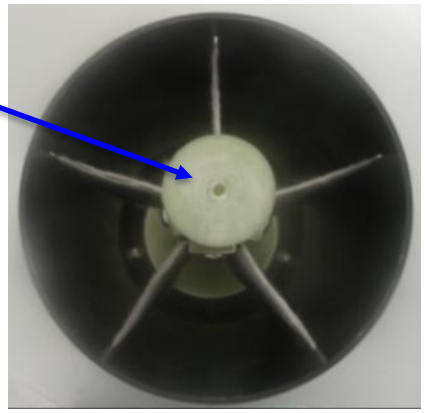


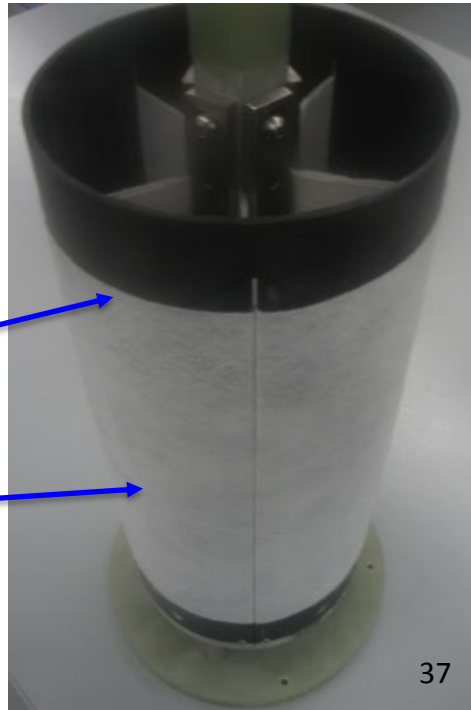


Coil Test Assembly







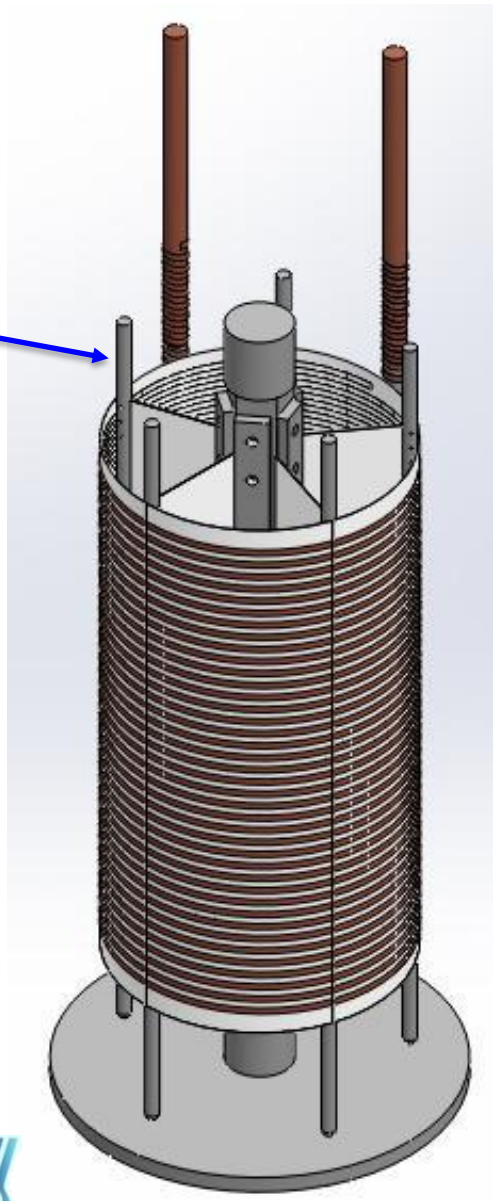


Fabric Cylinder

Expanded & Collapsed

Conductor Applied to Fabric

Coil movement indicators



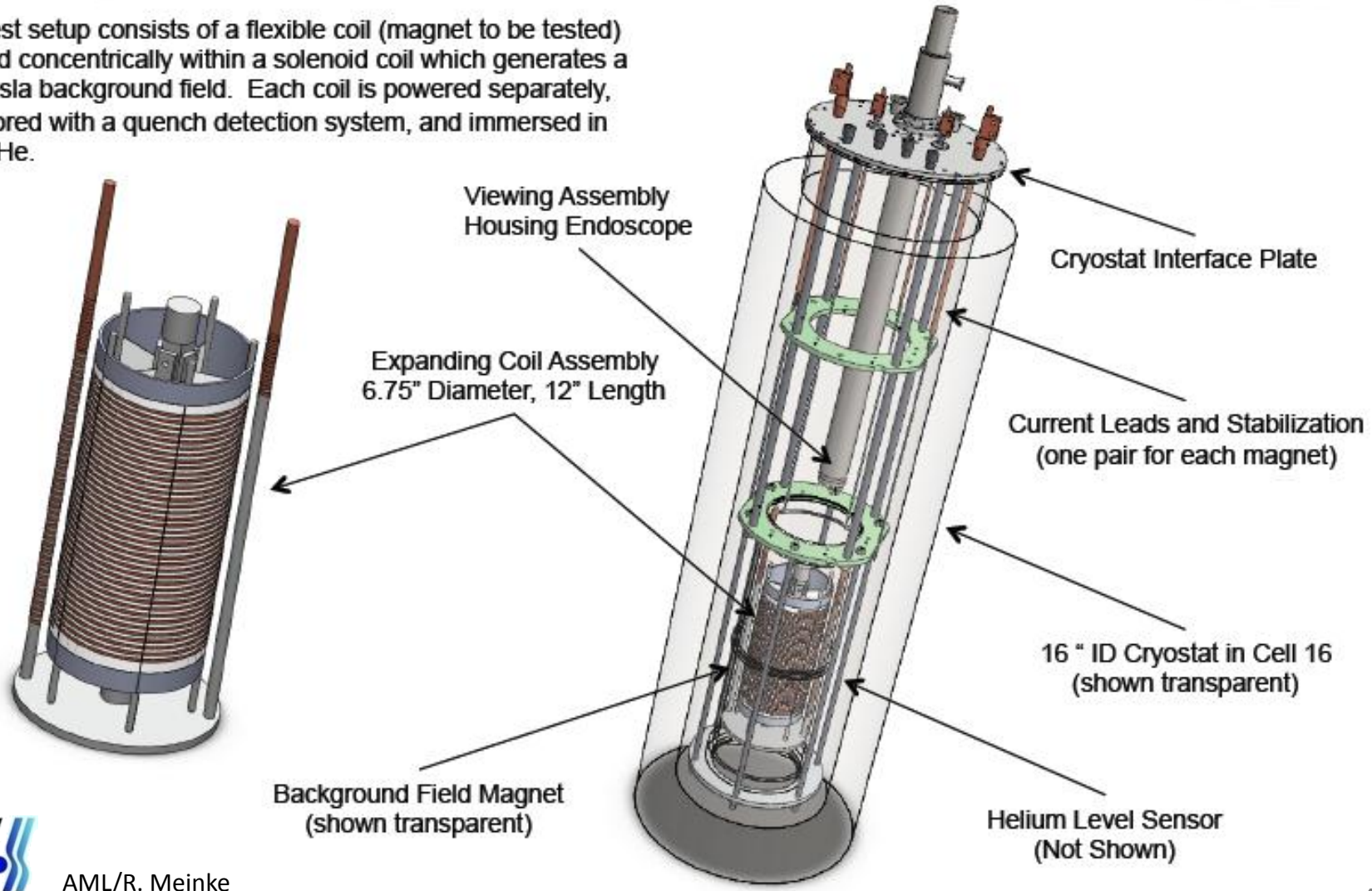
Advanced Magnet Lab

AML/R. Meinke

Expandable Coil Test Fixture

This test is scheduled to be conducted at the National High Magnetic Field Lab (NHMFL) at Florida State University in January, 2013

The test setup consists of a flexible coil (magnet to be tested) located concentrically within a solenoid coil which generates a 1-2 Tesla background field. Each coil is powered separately, monitored with a quench detection system, and immersed in liquid He.



Launch Configurations

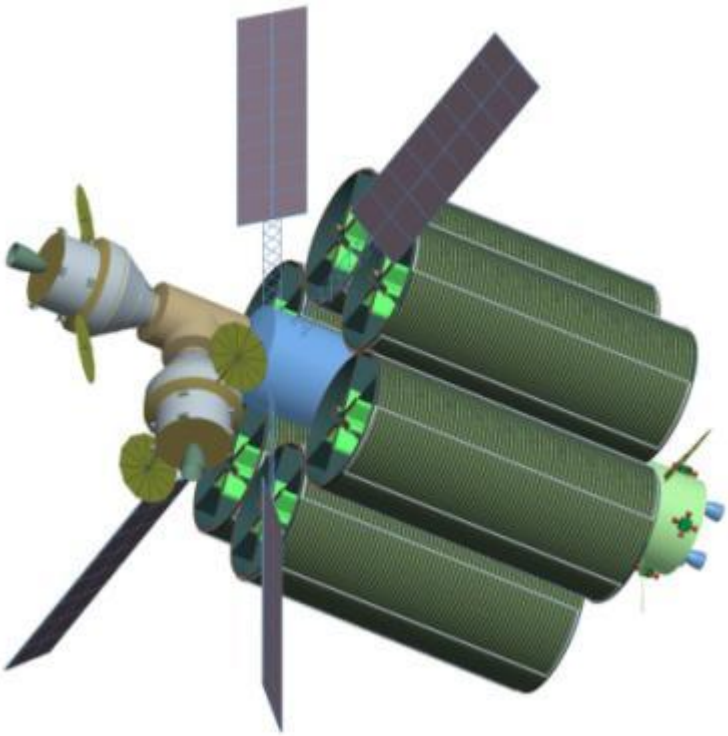
Launch 1

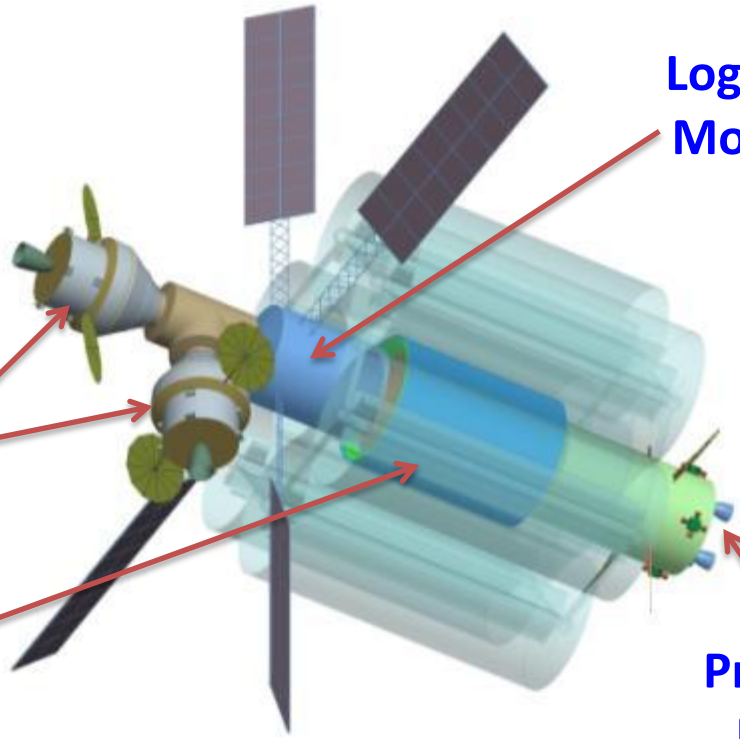
6 coils

Launch 2

Habitat with Compensation Coil

Low Earth Orbit Assembly





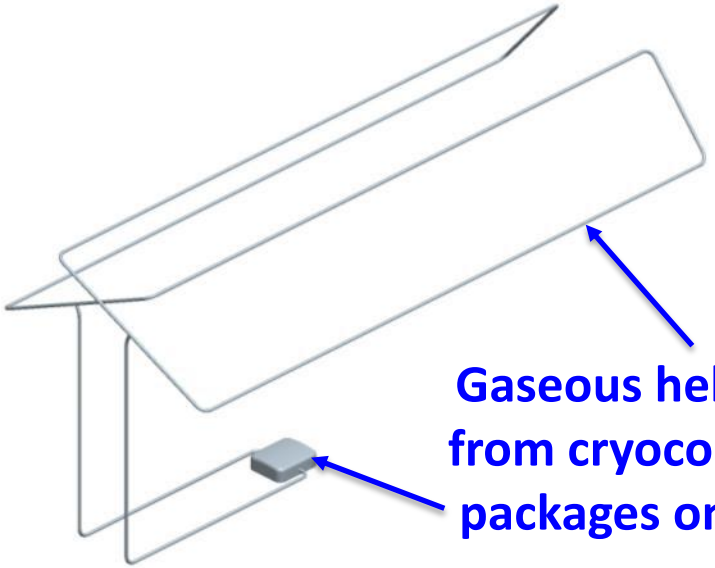
Logistics Module

Orion/MPCV

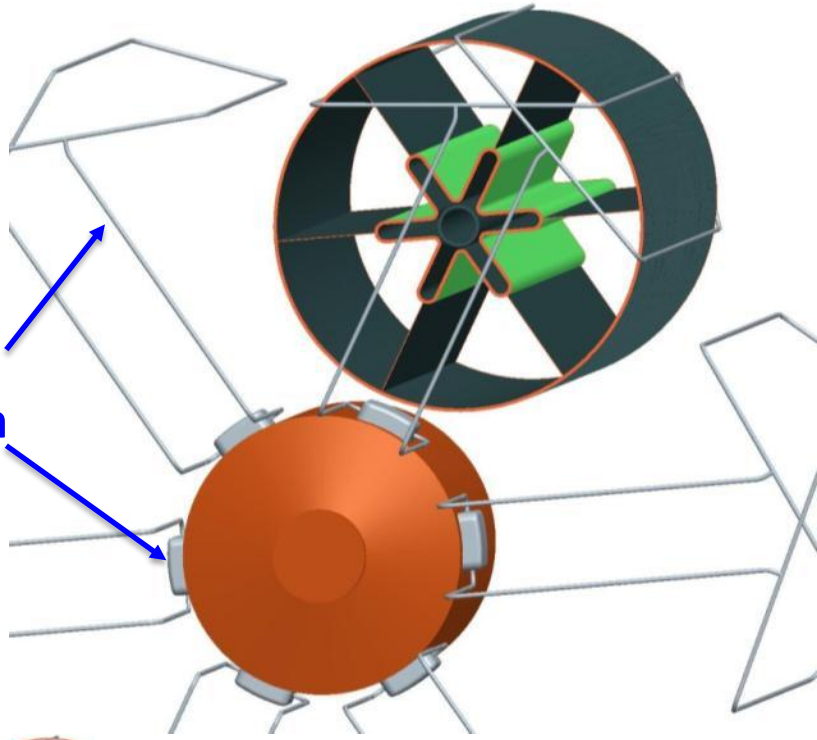
Habitat with Compensator Coil

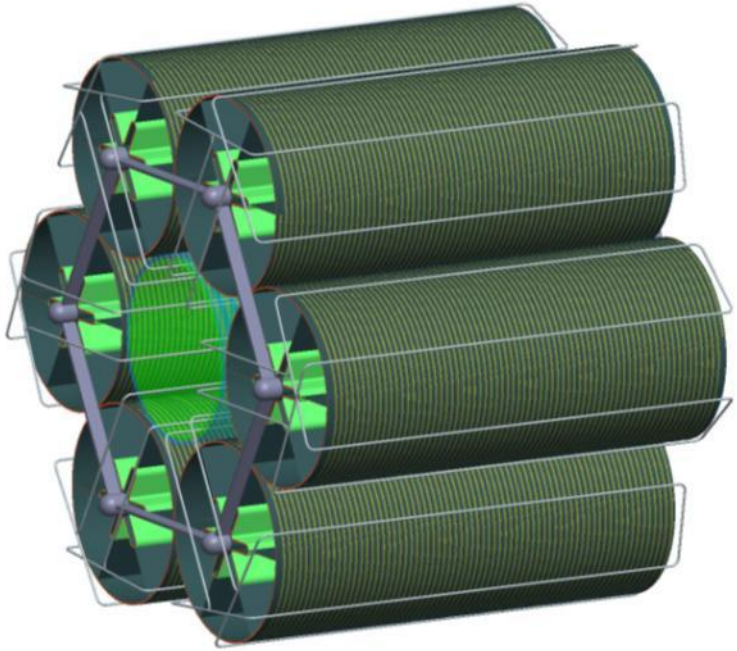
Propulsion Module

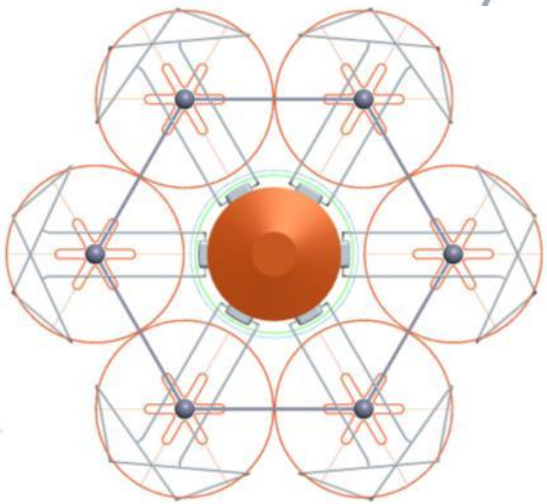
Thermal Management with Cryocoolers



Gaseous helium cooling lines from cryocooler/recirculation packages on Habitat Module

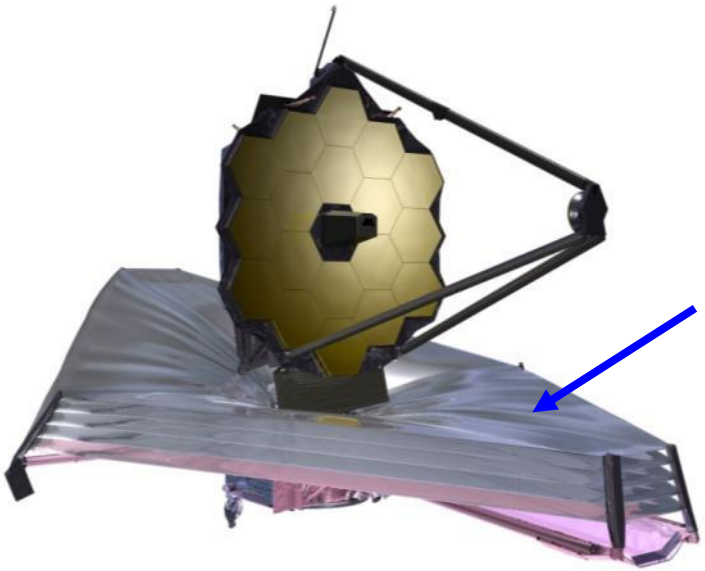




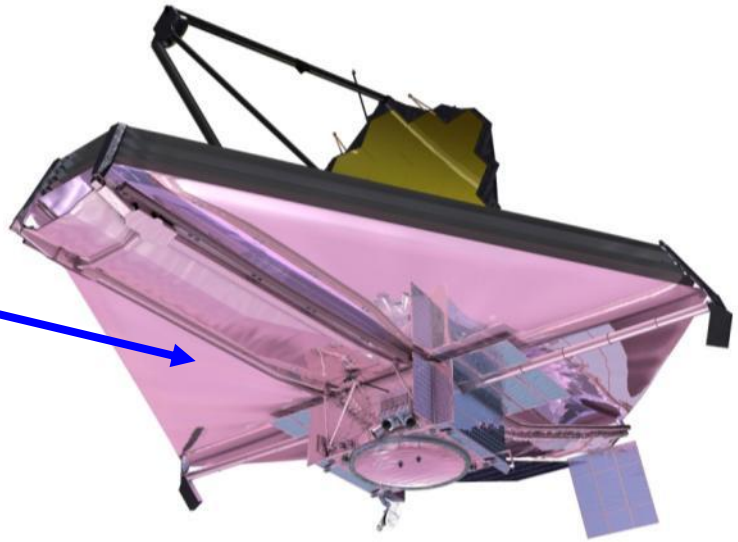


S Van Sciver – FSU

Thermal Management with Sunshield



JWST
Sunshield



SUNLIGHT

Earth

Additional
Solar Arrays

Mars

Sunshield

Mass & Power Estimates

6 Shield Coil Strongbacks & Conductors	19,300
Thermal Control Systems & blankets	17,800
Compensation Coil & Structure	2,400
~35% Contingency	13,800
TOTAL:	~53,300 kg

Power to charge and cool radiation shields: ~26 kW

Critical Technologies R&D

- HTS tape with higher current carrying capability and available in 10s of kilometer lengths
- Low resistance HTS joints
- Quench protection for HTS coils
- Large expandable superconducting magnet design and assembly
- Cryogenically stable & weight efficient structural materials
- Helium gas based recirculating cooling systems
- EVA cryogenic connections
- Flexible cryogenic gaseous helium lines
- More efficient low temp cryo-coolers
- Magnetic field flux charging devices
- Large scale superinsulation and heat removal at low temps
- Simulation techniques to understand the complex interaction between active and passive shielding

NASA Innovative Advanced Concepts