Compact HTS magnets for Neutron scattering sample environments

Taotao Huang, D Pooke, M Fee and V Chamritski

HTS-110 , New Zealand

Outline

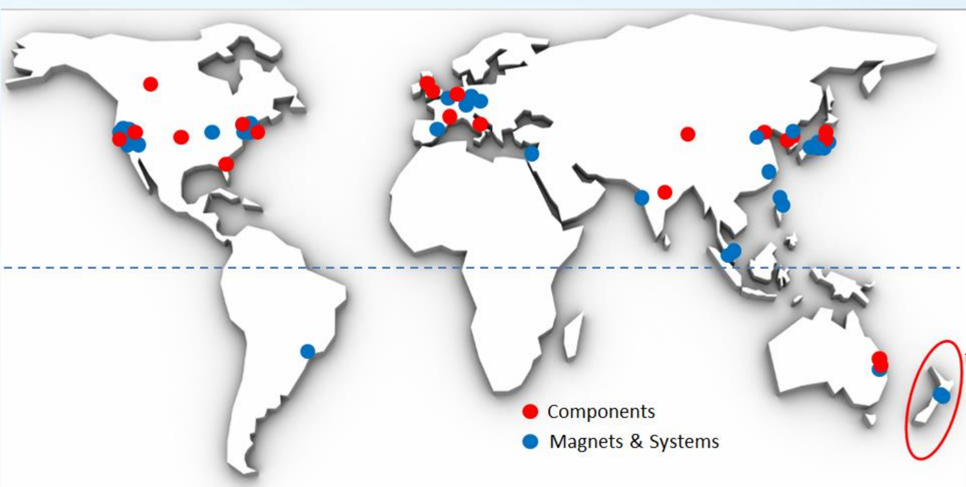
- Introduction
- Present LTS magnets for neutron scattering
- HTS vs LTS
- HTS magnet technology
- HTS neutron scattering magnet examples
- Summary

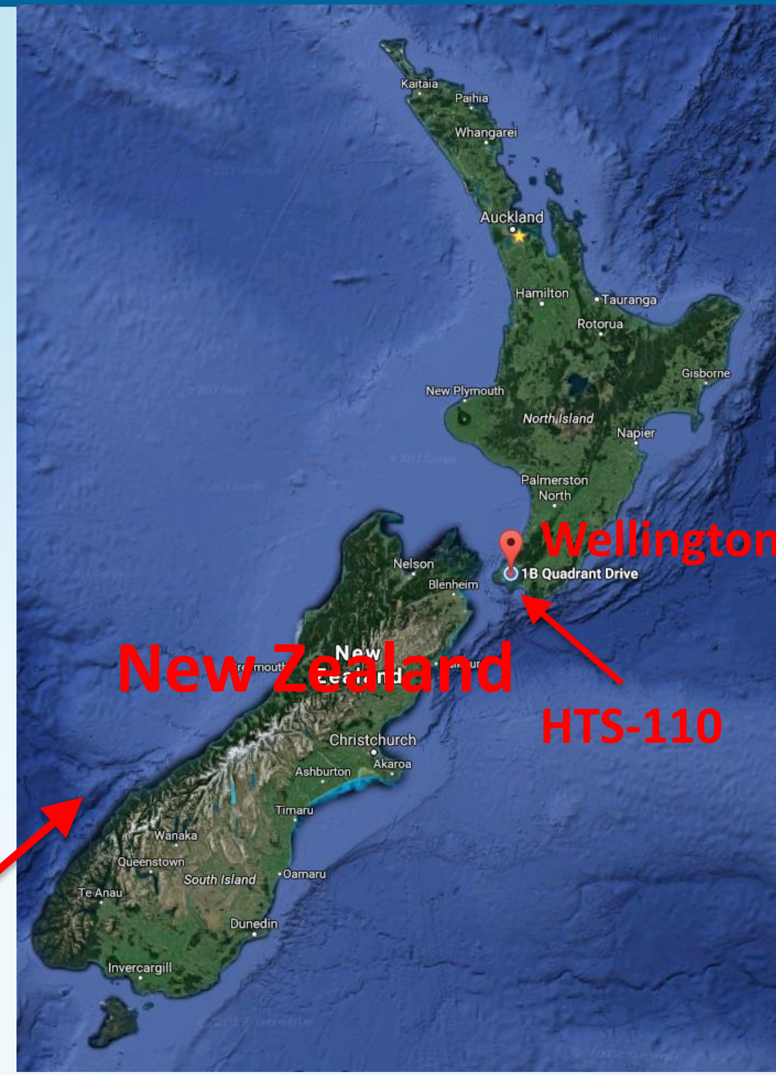
HTS-110

SCOTT

What is HTS-110

- HTS-110 is a New Zealand company specialising in the design and manufacture of HTS magnets
- Established in April 2004 building on 20 years of HTS R&D in government research labs.
- Owned by Scott Technology, a listed New Zealand company.





HTS-110

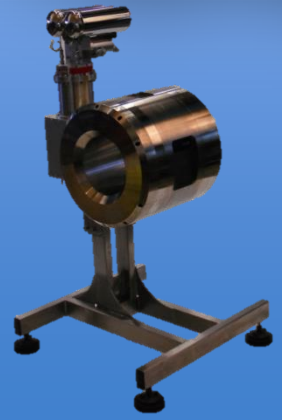
SCOTT

Cryogen-free HTS magnets by HTS-110

Neutron Scattering & Beam-line Magnets

Materials Analysis

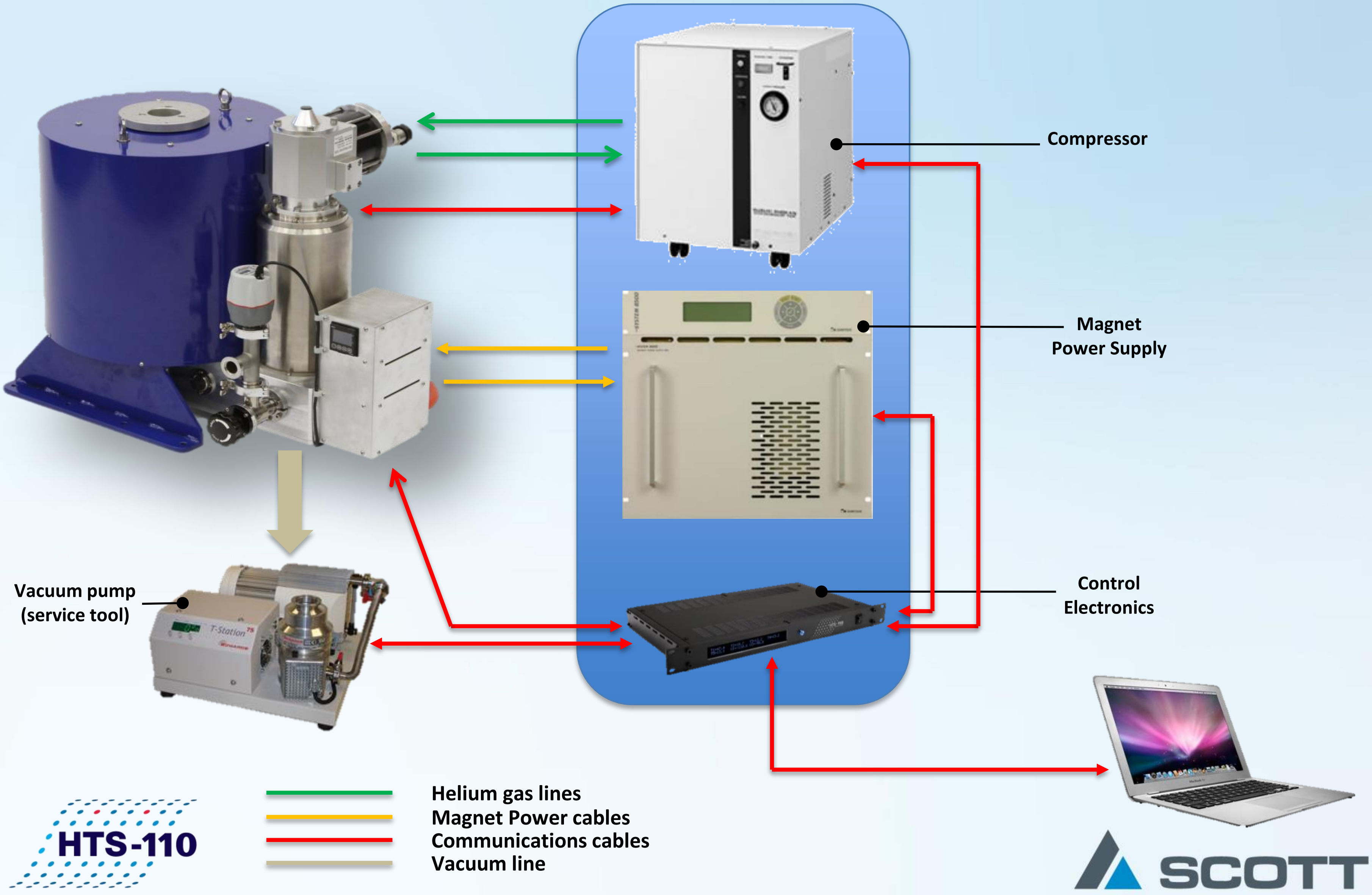
NMR & MRI



HTS-110

SCOTT

HTS magnet system

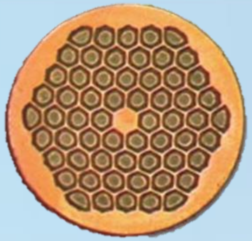


Present LTS magnets for neutron scattering

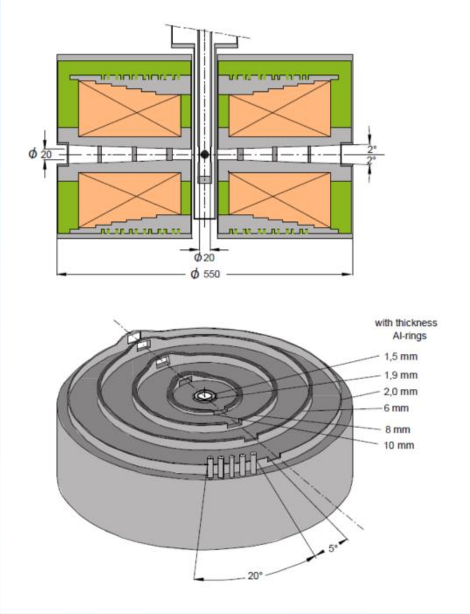
LTS Magnet technology

- Wire: NbTi or Nb_3Sn
- Split pair geometry
- Horizontal or vertical field configuration
- Symmetric or asymmetric mode (for polarised neutrons)
- Compatible with VTI
- Active shielding to reduce magnetic fringe fields
- Coil support with Aluminium rings, or "wedge" pillars
- Cooling: LHe, Recondensing and Cryogen-free

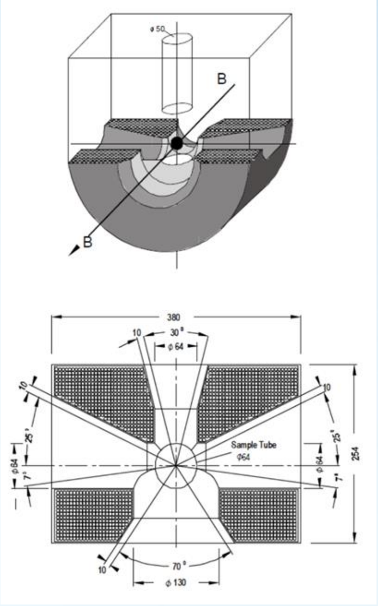
NbTi Wire in channel



Nb_3Sn wire



Vertical configuration



Horizontal configuration

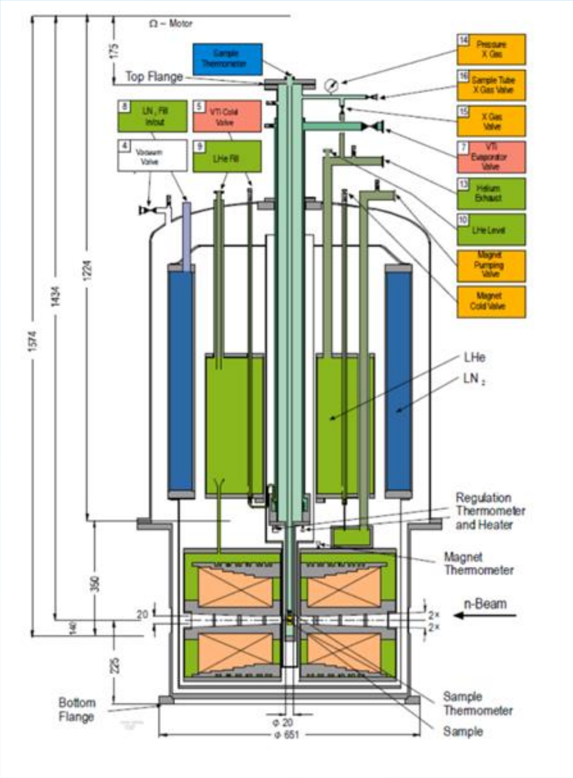
HTS-110

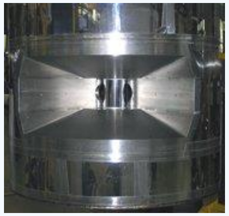
SCOTT

Commercial LTS magnet for neutron scattering

Typical performance

- Field strength up to 15 T at 2.2 K and 13.5 T at 4.2 K
- Field strength up to 10 T for cryogen free system
- Split-pair geometry
- Vertical field configuration
- Homogeneity over 10 mm DSV: 0.5%
- Split at magnet centre line: 20 mm
- Split angle ±2°
- Neutron access in horizontal plane: 330°
- Al thickness: ~30 mm





https://www.oxford-instruments.com/industries-and applications/research/neutron-scattering

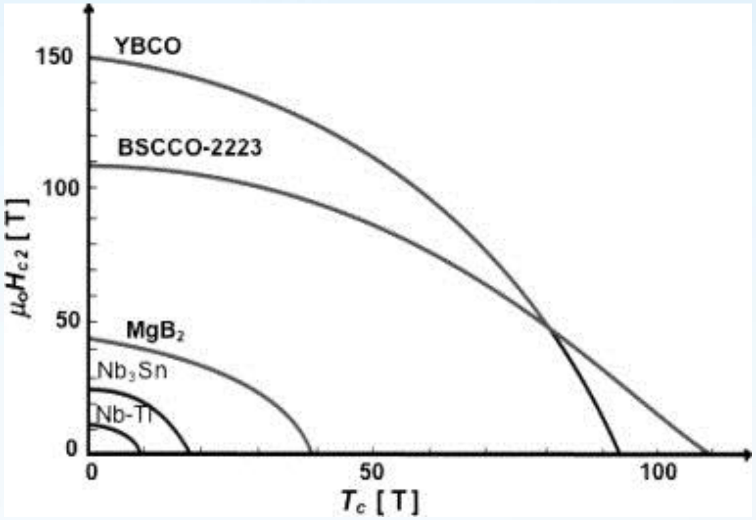
HTS vs LTS

Advantages

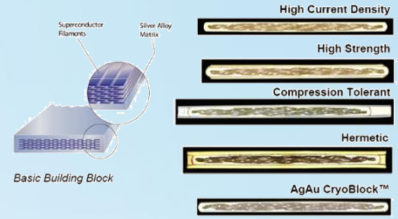
- High Tc (Top>10 K, HTS indispensable)
- Ultra-high field (B > 25 T @ 4.2K, HTS indispensable)

Setbacks

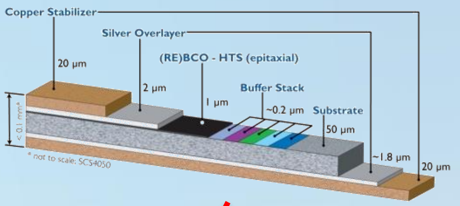
- In-field anisotropy
- Still expensive

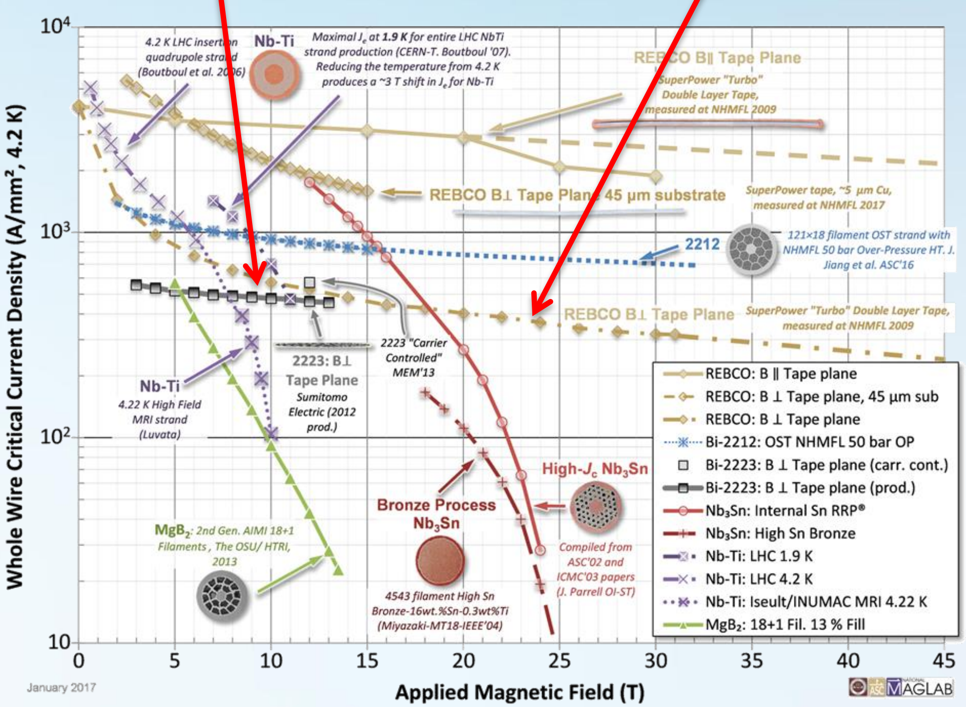


1G BSCCO tape



2G YBCO tape





Plot from: https://nationalmaglab.org/images/magnet_development/asc/plots/

HTS offers benefits to magnets

What High T_c means for magnet designer

- Simple cryogenics
- Very stable, hardly quench
- Stiff suspension
- Low power cooling

What HTS Magnets means for Users

- **Easy to use**
- **Flexible**
- **Combined**
- **Saving time, saving space and saving money**

What HTS technology offers to neutron scattering sample environments

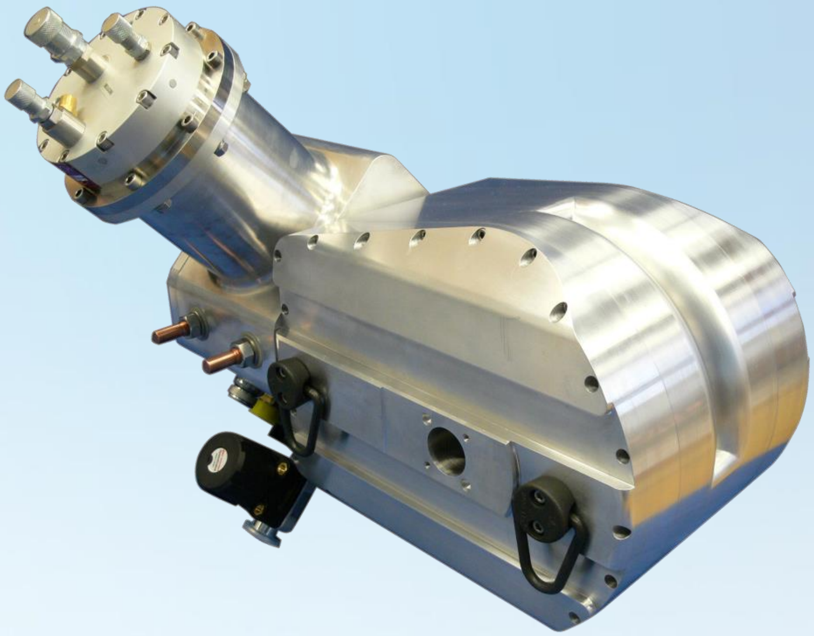
- Cryogen free
- Compact
- low fringe field
- Fast ramping
- Fast cooldown
- Mobile
- Any field orientation
- RT bore compatible with commercial sample cryostats
- RT aperture with no material in neutron beams to cause scattering background
- Symmetric split-pair possible for polarization analysis

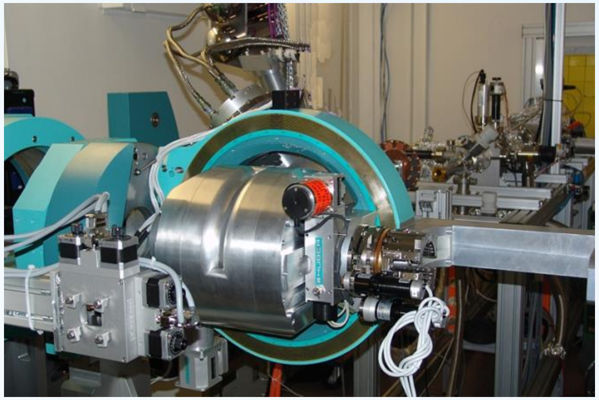
HTS-110

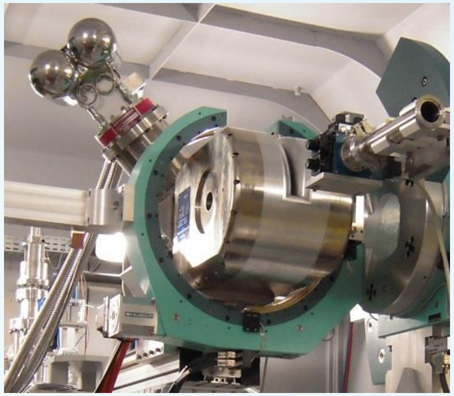
SCOTT

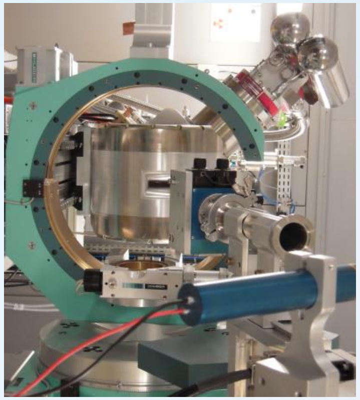
An example of HTS Magnets

- System designed for x-ray resonant magnetic scattering and high resolution diffraction
- Vertical and horizontal fields up to 6 Tesla
- Ø40mm room temperature bore, compatible with sample cryostats
- Scattering angle up to 120°
- Goniometer mounted for 90 degree rotation
- Compact size and low mass allowing them to be fitted inside an Eulerian cradle
- Weight: 100 kg





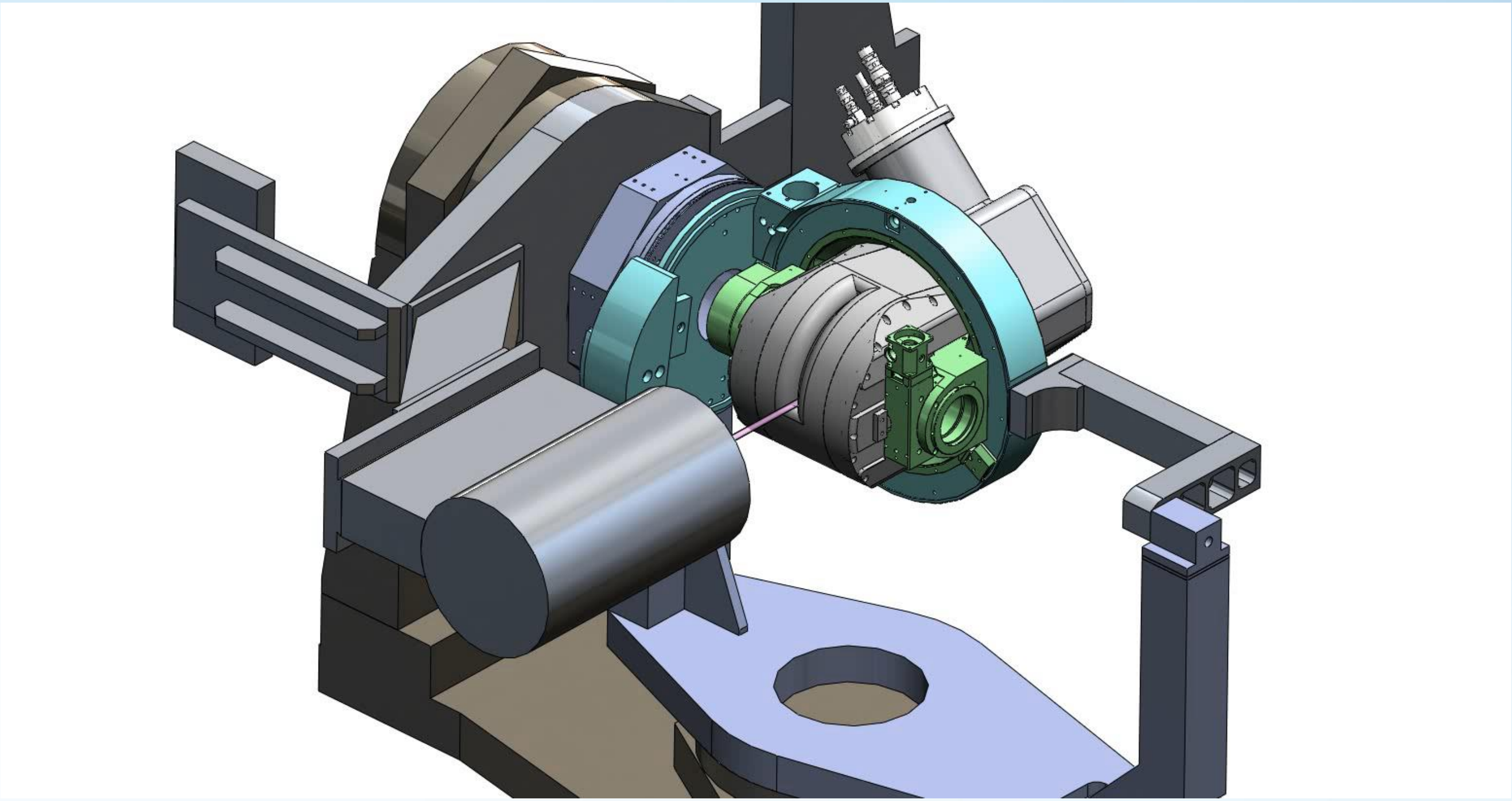




HTS-110

SCOTT

5-6 Tesla HTS beamline Magnet



HTS-110

SCOTT

HTS magnet design – Concept an Constraints

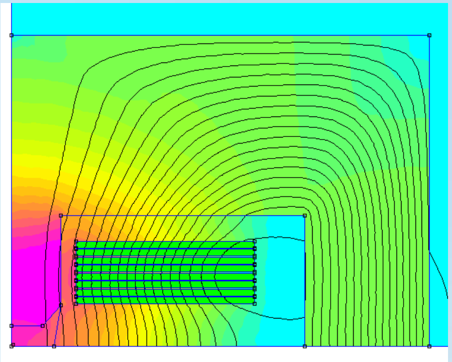
'Classic' HTS-design with split-pair coil-packs and shaped iron poles and yoke. The yoke also functions as a vacuum cryostat.

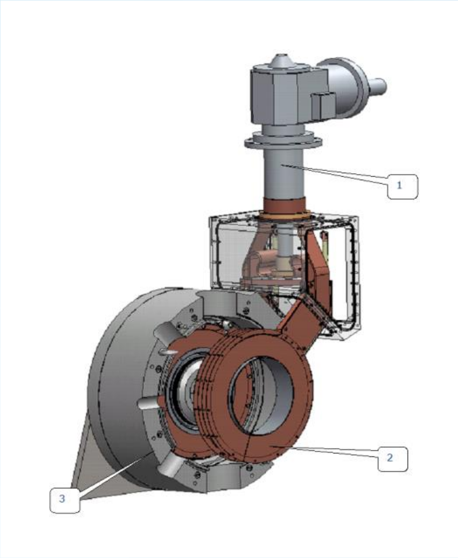
Two-stage cryocooler with heat extraction from leads minimises coil-temperature rise at high operating currents

Even at high fields well above iron saturation a ferromagnetic yoke can:

- increase peak achievable field magnitude.
- efficiently reduce stray fields.
- minimise perpendicular field effects on coil Ic.

But care must be taken in design to balance and counteract significant on-axis and off-axis mechanical forces.





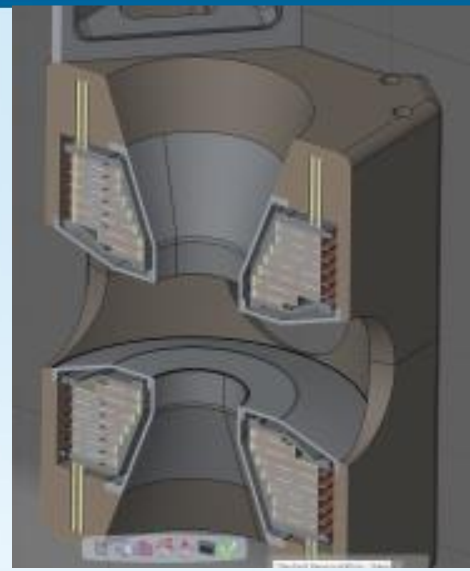
Schematic of the HTS magnet: cryocooler(1), HTS coil pack (2) and cryostat (3).

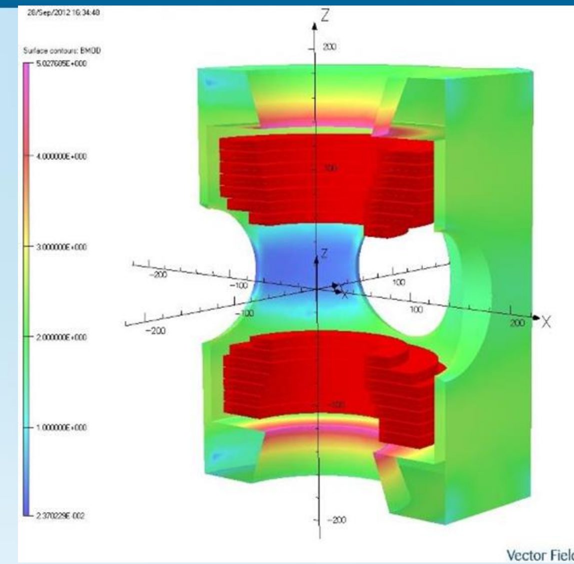
HTS-110

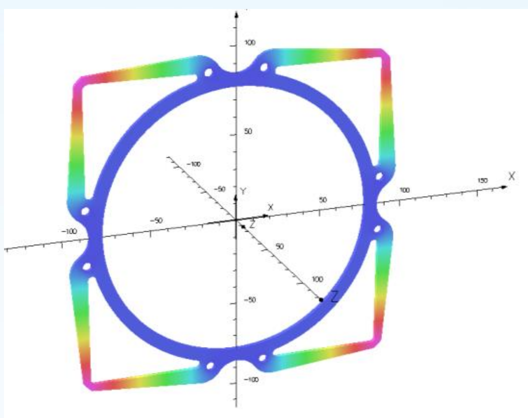
SCOTT

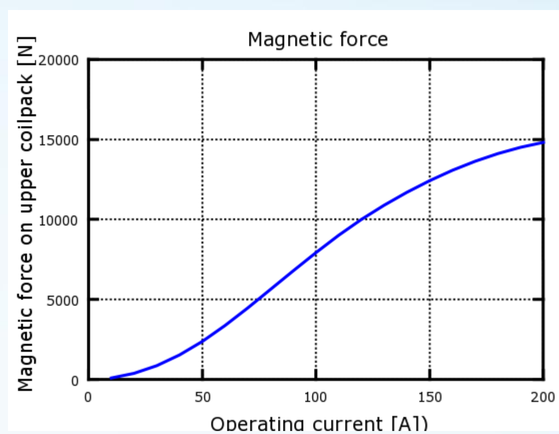
Magnet Design- Coil support

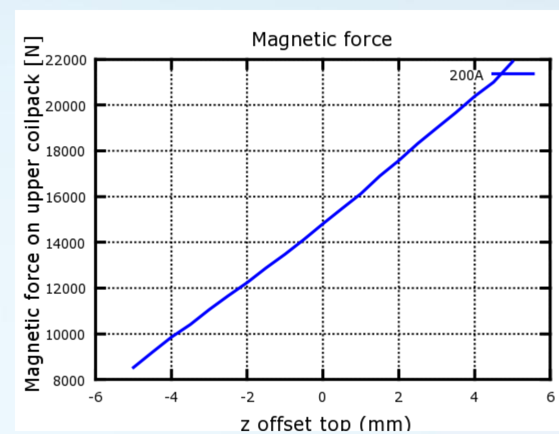
- Repulsive forces make Aluminium rings or wedge pillars redundant
- Stiff axial and radial support to allow magnets to be oriented in any directions
- Big RT aperture possible











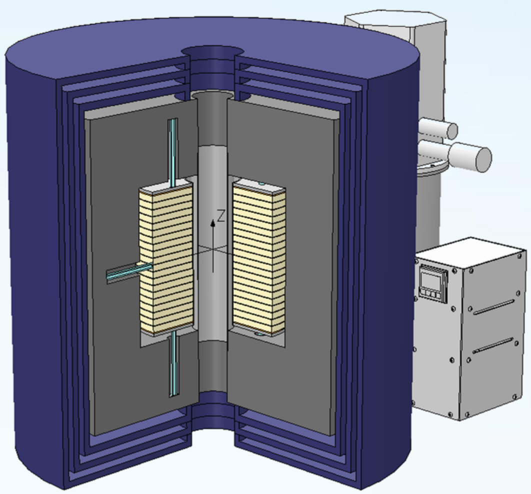
HTS-110

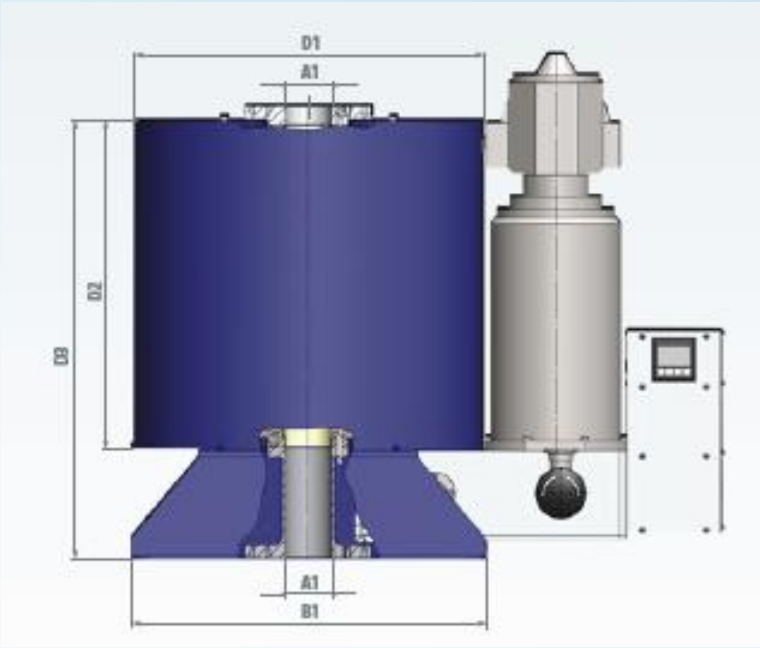
SCOTT

Magnet design – Passive shielding

- Low stray field 5 Gauss < 300 mm from the centre of a 4.7 T solenoid magnet
- Low stray field 5 Gauss < 400 mm from the centre of a 9.4 T solenoid magnet

Model	Magnetic Field (MHz)	Bore size (mm)	5 Gauss (mm) Axial/Radial	Uniformity (PPM)[1]	Magnet Height (mm)	Magnet Width (mm)
MR 4T7-54	200	54	<100/50	<1	400	360
MR 9T4-54	400	54	<200/100	<1	600	600





HTS-110

SCOTT

Magnet design – Fast ramping

Significant improvements in performance over the past five years as we develop engineering solutions to minimise and mitigate the effects of eddy current losses and AC losses in fast-ramp magnet designs

First commercial high-field fast-ramp

- +/-7T ~50 mT/sec. (plus 25% dwell time)

Current fast-ramp systems

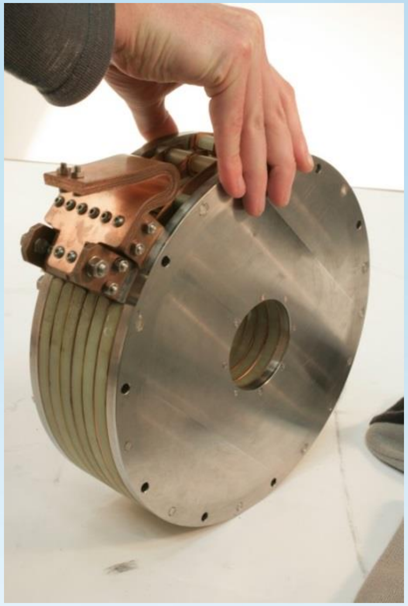
- +/-7T @ >100 mT/sec. continuous
- +/-6T @ 250 mT/sec. continuous
- +/-7T @ 450 mT/sec. continuous

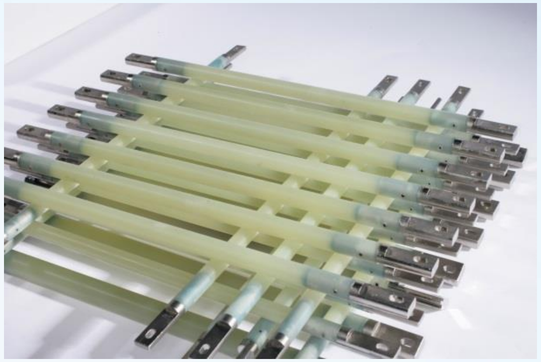
HTS-110

SCOTT

HTS magnet production in HTS-110

- Wire test
- Coil winding
- HTS current leads
- Coil impregnation
- Coil LN2 Test
- Coil pack assembly
- Magnet assembly and integration





HTS-110

SCOTT

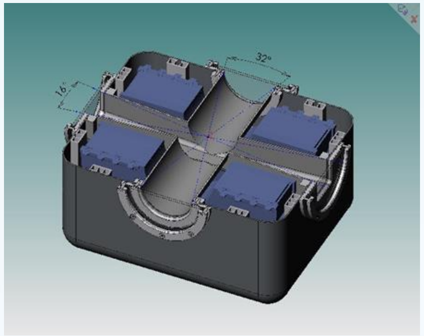
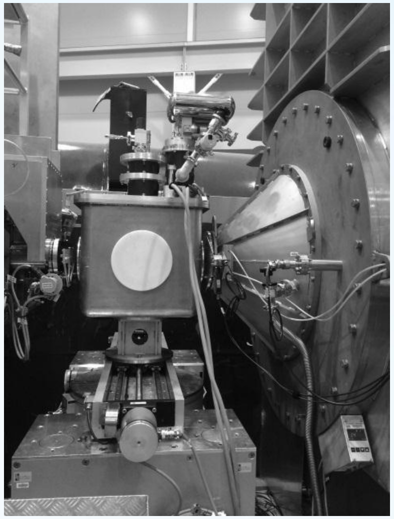
5 Tesla Neutron scattering magnet

Application:

- Small-angle neutron scattering (SANS)
- Neutron diffraction and reflectometry

Features:

- Horizontal field up to 5 T
- > 44 mm pole gap
- Wide beam accessibility angles (±8-12° in the transverse direction and ±16° in the axial direction)
- Goniometer mounted for tilting up to 15 degrees


HTS-110

SCOTT

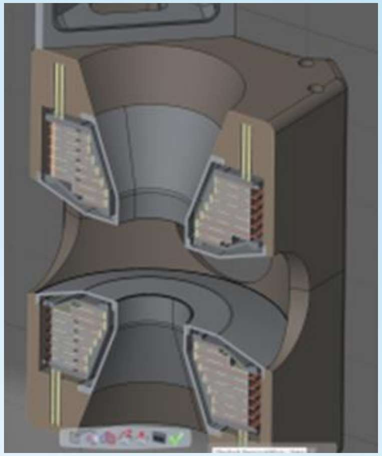
2.2T magnet for neutron time-of-flight (TOF) scattering

Application:

- Neutron diffraction
- Neutron reflectometry
- Time of Flight (TOF) scattering

Features:

- Vertical and Horizontal fields up to 2.2 T
- 80 mm pole gap
- 4 X Ø80 mm RT bore
- 150° horizontal scattering angle
- ± 20° vertical angle of aperture
- Operation in any orientation
- Cool-down time: 22 hours
- Weight: 186 kg
- Dimensions: 596 X 363 X 794 mm



HTS-110

SCOTT

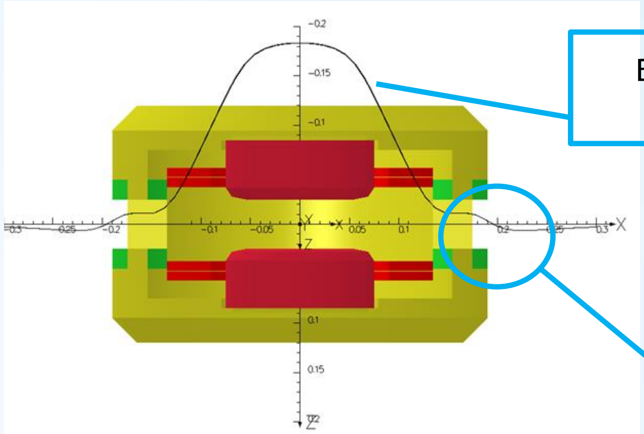
3 Tesla Neutron scattering magnet

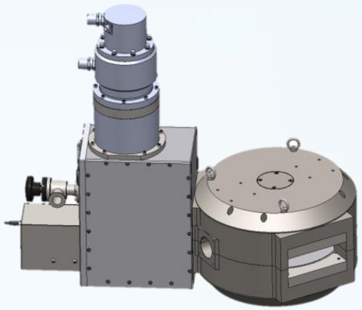
Application:

- Polarized neutron reflectometry

Features:

- Vertical field up to 3 T
- 52 mm pole gap
- Sample (beam) access: 52 X 160 mm
- Ø52 mm transverse access
- Cool-down time: 30 hours
- Fringe field: < 5 Gauss (at 1 m)
- Weight: 180 kg
- Dimensions: 711 X 577 X 684 mm
- Optional magnetic field entry/exit correction





HTS-110

SCOTT

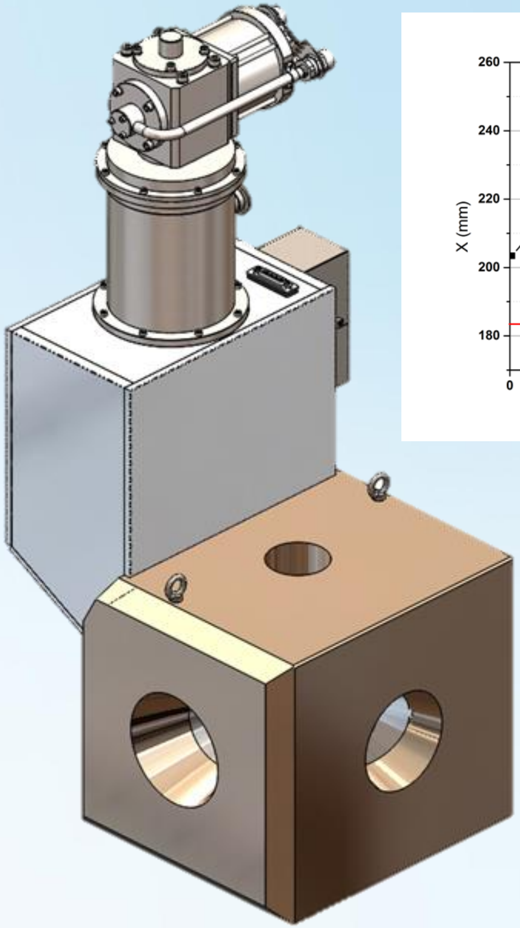
3 Tesla Neutron scattering magnet

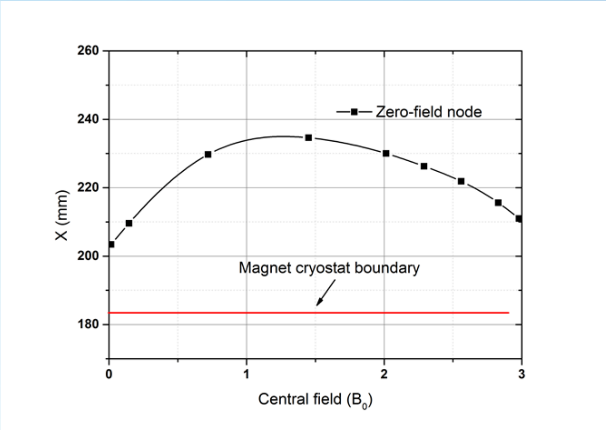
Application:

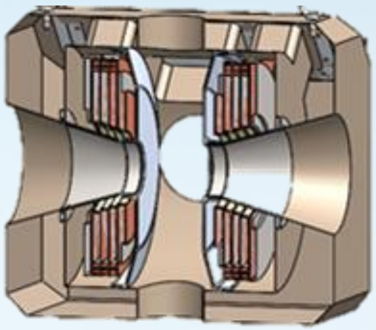
- Neutron diffraction
- Polarized neutron reflectometry

Features:

- Horizontal field up to 3.0 T
- 80 mm pole gap
- Sample volume: 25 mm DSV
- Ø80 mm vertical RT bore
- 4 X Ø60 mm horizontal RT bore
- 32° horizontal opening angle
- Zero-field nodes outside the magnet cryostat
- Fringe field: < 1 Gauss (at 1 m) in radial direction, <10 Gauss (at 0.5 m) in axial direction
- Weight: 340 kg
- Dimensions: 471 x 504 x 998 mm







HTS-110

SCOTT

Summary

HTS technology offers to neutron scattering sample environments

- Higher fields (>15 T @ T_{op} 4.2 K)
- Medium fields (2-10 T @ T_{op} > 10 K)
- Compactness and low fringe fields for saving your space
- RT bore and aperture allow flexibility to your sample cryostats and instrumentations
- Fast ramping and fast cool-down for saving you time
- Combined vertical and horizontal configuration for saving your money
- Symmetric mode plus low fringe field for polarized neutron

Since establishment in 2004, HTS-110 successfully designed and manufactured many challenging magnet systems around the world, using HTS technology.
We are dedicated to finding HTS solutions to serve neutron scattering sample environment society.

HTS-110

SCOTT