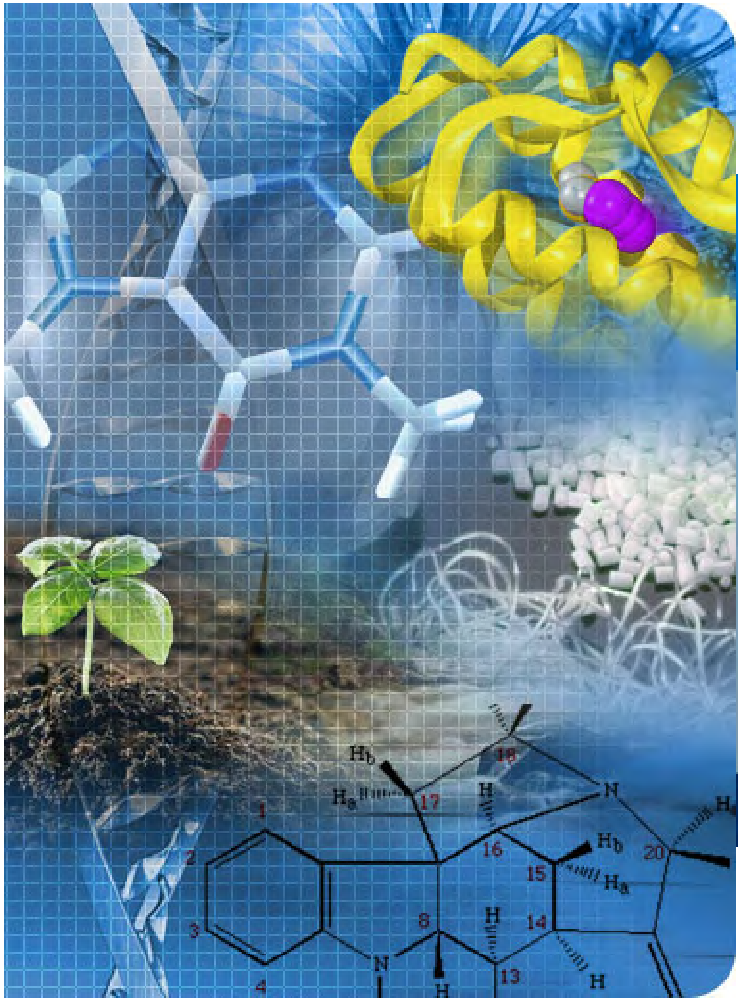


# World's highest field actively shielded split coil magnet for neutron scattering

R. Gilardi, Switzerland

# Outline

- Bruker magnet production and technology
- 16T actively shielded split coil magnet
  - Magnet
  - Cryostat
  - VTI
- Timeline of the project

# Bruker Corporation

**Bruker Corporation**

**Bruker AXS**

Analytical **X-ray systems** for elemental analysis, materials research and structural investigations

**Bruker BioSpin**

Worldwide technology and market leader in **NMR**, **EPR** and preclinical **MRI**

**Bruker Daltonics**

Life science tools based on **mass spectrometry** and broad line of **detection products**

**Bruker Optics**

Analysis instruments based on **infrared and Raman molecular spectroscopy**

*Billerica*
United States

*Faellanden*
Switzerland

*Rheinstetten*
Germany

*Wissembourg*
France

# Magnet Production at Bruker BioSpin

- NMR Magnets
  - Up to 22.3T (950 MHz)
- Laboratory Magnets
  - Up to 21 T
- FTMS Magnets
  - Up to 15 T
- MRI Magnets
  - Up to 11.4 T
- EPR Magnets
  - Up to 12 T
- Gyrotron Magnets
  - Up to 9.7 T



# Magnet Production in Switzerland

- Coil Winding
- Magnet Assembly
- Cryostat Assembly
- Test Laboratory


> 500 employees in
Fällanden, Zurich

Development: 30%
Production & Test: 58%
Administration & Sales: 12%

# Magnet Technology

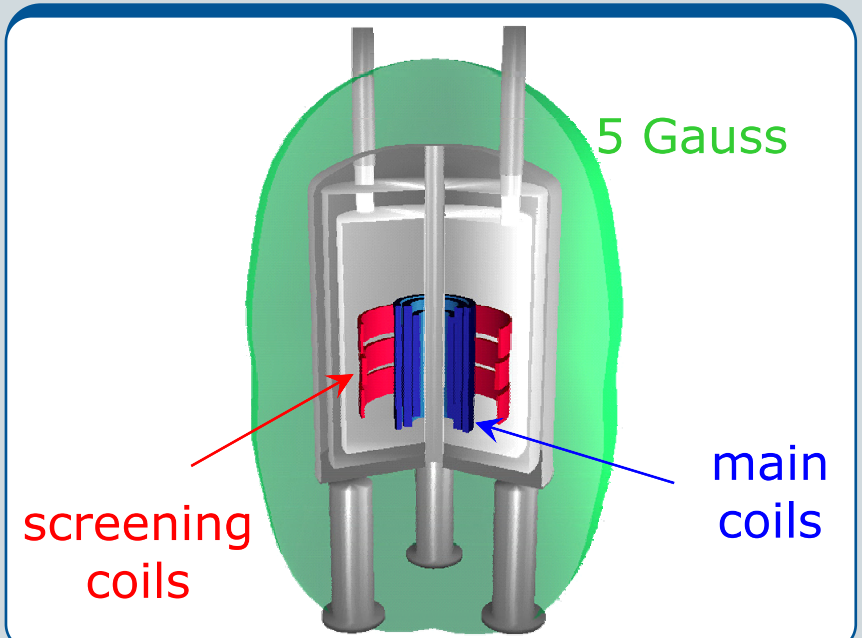
- **Superconducting wire technology**
  - NbTi
  - $Nb_3Sn$ (wind & react)
  - HTS
  - $MgB_2$
- **Active shielding technology**
  - Multiple coil design with opposite polarity to compensate dipole moment
  - Reduction of stray fields
- **Electromagnetic Disturbance Suppression**
  - Screening against external electromagnetic field disturbances

EAS

**E**uropean
**A**dvanced
**S**uperconductors

EHTS

European High Temperature Superconductors
A member of Bruker Biospin



# Cryogenic Technology

- **Sub-Cooling**
  - Reducing the operating temperature of the superconducting material from 4.2K to 2.2K in order to achieve the highest possible field strength
- **Active cooling**
  - Nitrogen-free compact superconducting magnets with very low or no Helium losses (zero-boil-off)
- **Cryogen free**
  - Cooling the magnet without the use of liquid cryogens
- **Variable Temperature Insert**
  - Adjust the temperature of the sample from 2K to 300K

# Outline

- Bruker magnet production and technology

- 16T actively shielded split coil magnet
  - Magnet
  - Cryostat
  - VTI

- Timeline of the project

# Split coil magnet systems for neutron scattering

| Requirements for neutron scattering | Commercially available magnet systems | New Bruker magnet system |
| --- | --- | --- |
| High magnetic field in symmetric mode | <15 T | ± 16 T |
| High magnetic field in asymmetric mode (experiments with polarized neutrons) | ≤ 12 T | ± 14 T |
| Small stray fields | Unshielded magnets ➪ large stray fields | Actively shielded magnet ➪ small stray fields |
| Field homogeneity | Typically 1% in 10mm DSV | <0.5% (symmetric mode)<br><1% (asymmetric mode) |

# Split coil magnet system for neutron scattering

| Requirements for neutron scattering | New Bruker magnet system |
|---|---|
| Large split size and conical angle | - Split conical angle = ±4°<br>- Max. sample height=16mm (visible by horizontally incoming neutrons) |
| Open access for incoming and scattered neutrons | - 330° neutron access in horizontal plane (Al-windows, Al-rings, no liquid helium in the neutron beam)<br>- Open access in Al-rings along beam line |
| Variable temperature insert (VTI) | - ILL-type<br>- Internal diameter at sample position = 34 mm<br>- Temperature range: 2 K < T < 300 K<br>- Compatible with dilution refrigerator and high-temperature inserts. |

# Split coil magnet system for neutron scattering

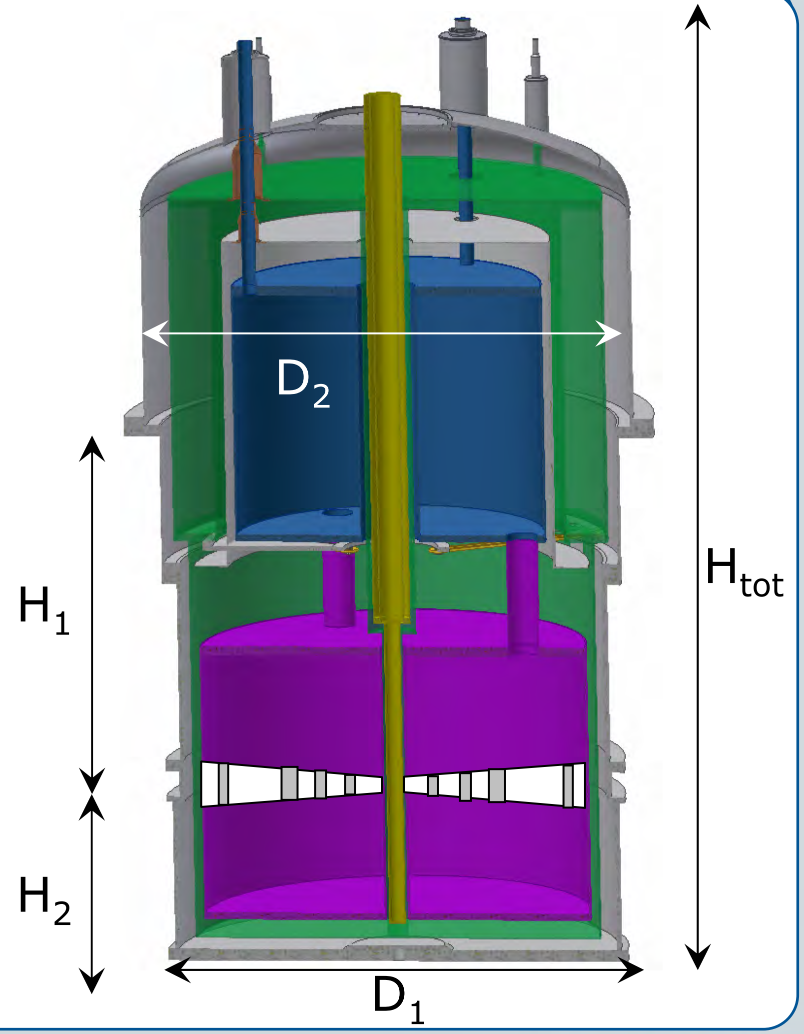
| Requirements for neutron scattering | New Bruker magnet system |
|---|---|
| Persistent mode operation | Possible in both symmetric and asymmetric mode |
| Field stability | Drift ≤ 0.02%/h |
| Short energizing time | Ramp time to maximal field @4.2K ~ 80 min |
| Long cryogen hold time | - Low-loss HTS current leads<br>- LHe hold time at 4.2 K > 4 days<br>- LHe hold time at 2.2 K > 1 day<br>- $LN_2$ hold time > 4 days |
| Cryostat tilt | Up to 2°(energized magnet) |
| Cold transport between instruments | Possible (de-energized magnet) |

# Split coil magnet system for neutron scattering

| Requirements for neutron scattering | New Bruker Magnet System |
|---|---|
| Ease of use | - Operation at 4.2 K up to 14.5 T / 12.5 T (symmetric / asymmetric mode)<br>- Automatic Cooling Device<br>- LabVIEW™ magnet control program<br>- $LN_2$ and LHe level sensors with display<br>- Heat exchangers on $N_2$ tower to avoid condensation and freezing of water<br>- Connector board and gas handling panel |
| Safety | - Protection against quench and power failure<br>- Auto-run-down<br>- Magnet monitoring in power supply<br>- Quench detection |

# System dimensions

| | |
|---|---|
| Height of the overall cryostat body $H_{tot}$ | ~ 2200 mm |
| Distance $H_1$ from magnetic center to body flange | 749.3 ± 2.54 mm |
| Distance $H_2$ from magnetic center to cryostat base | 381 ± 2.54 mm |
| Diameter $D_1$ of cryostat below body flange | ~ 977 mm |
| Diameter $D_2$ of cryostat above body flange | ~ 1100 mm |
| System weight | ~ 2 tons |



# Concept of actively shielded split coil magnets

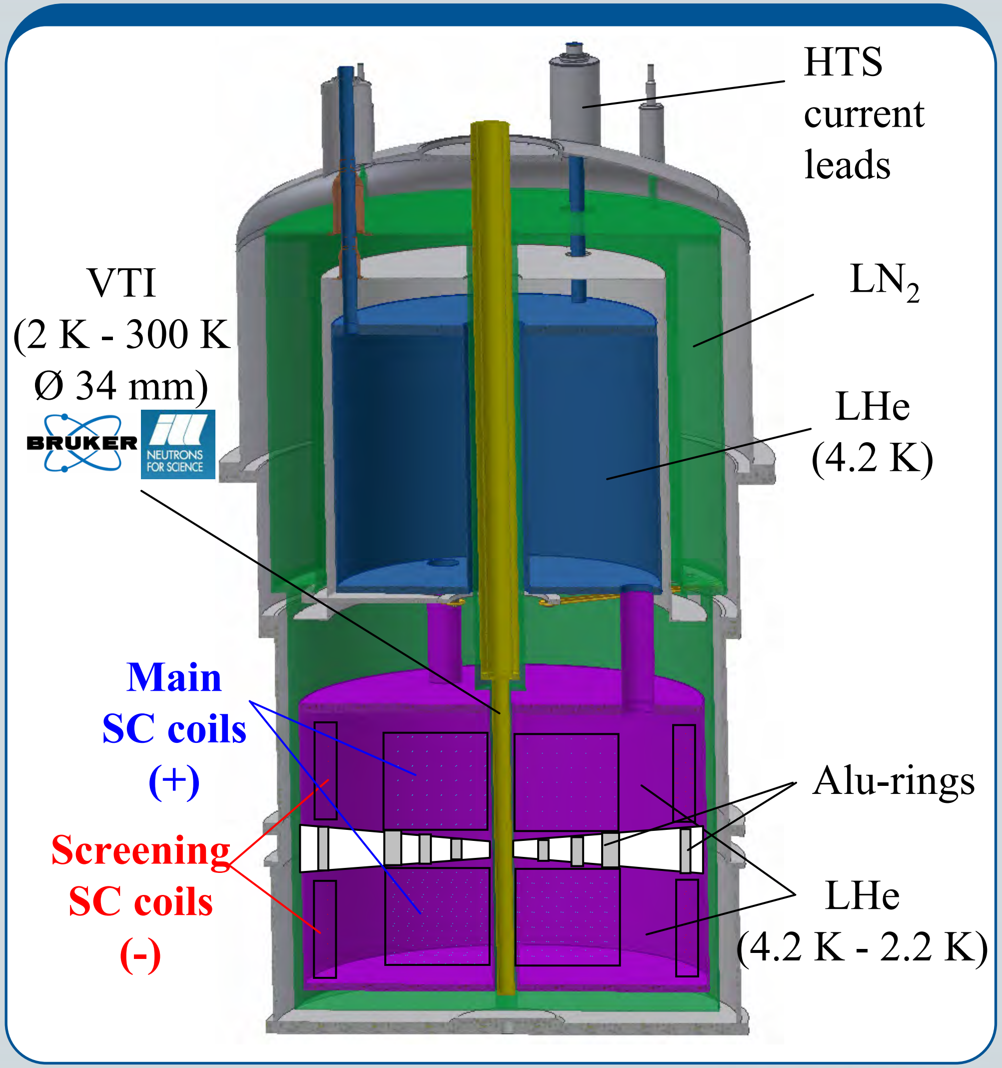
Stray field is undesired because of:

- Forces on ferromagnetic objects
- Disturbance of electronics, PC, …
- Credit cards, pacemakers

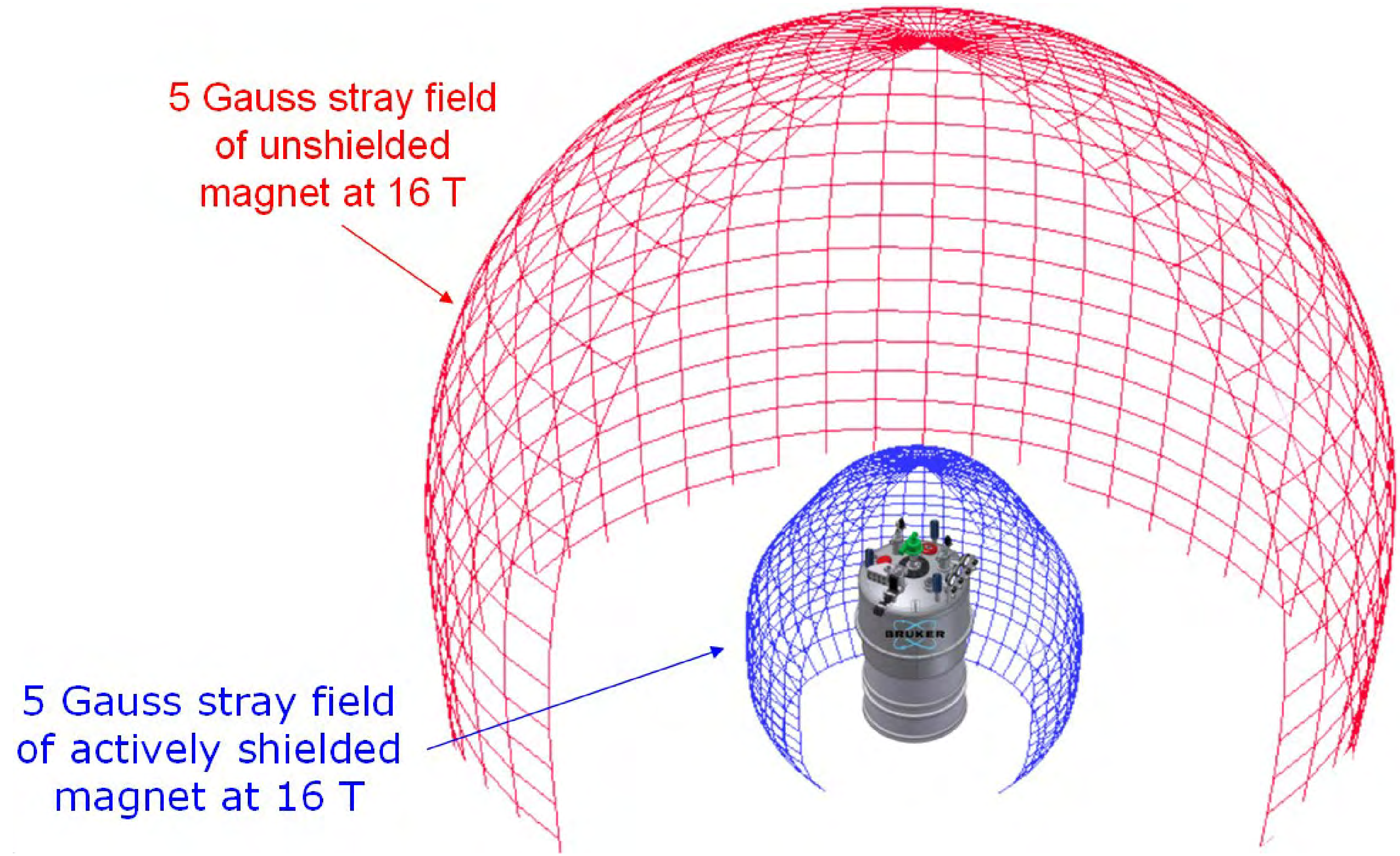
In particular for neutron scattering experiments:

- Disturbance of He3 spin filters (experiments with polarized neutrons)
- Disturbance of neighbouring instruments

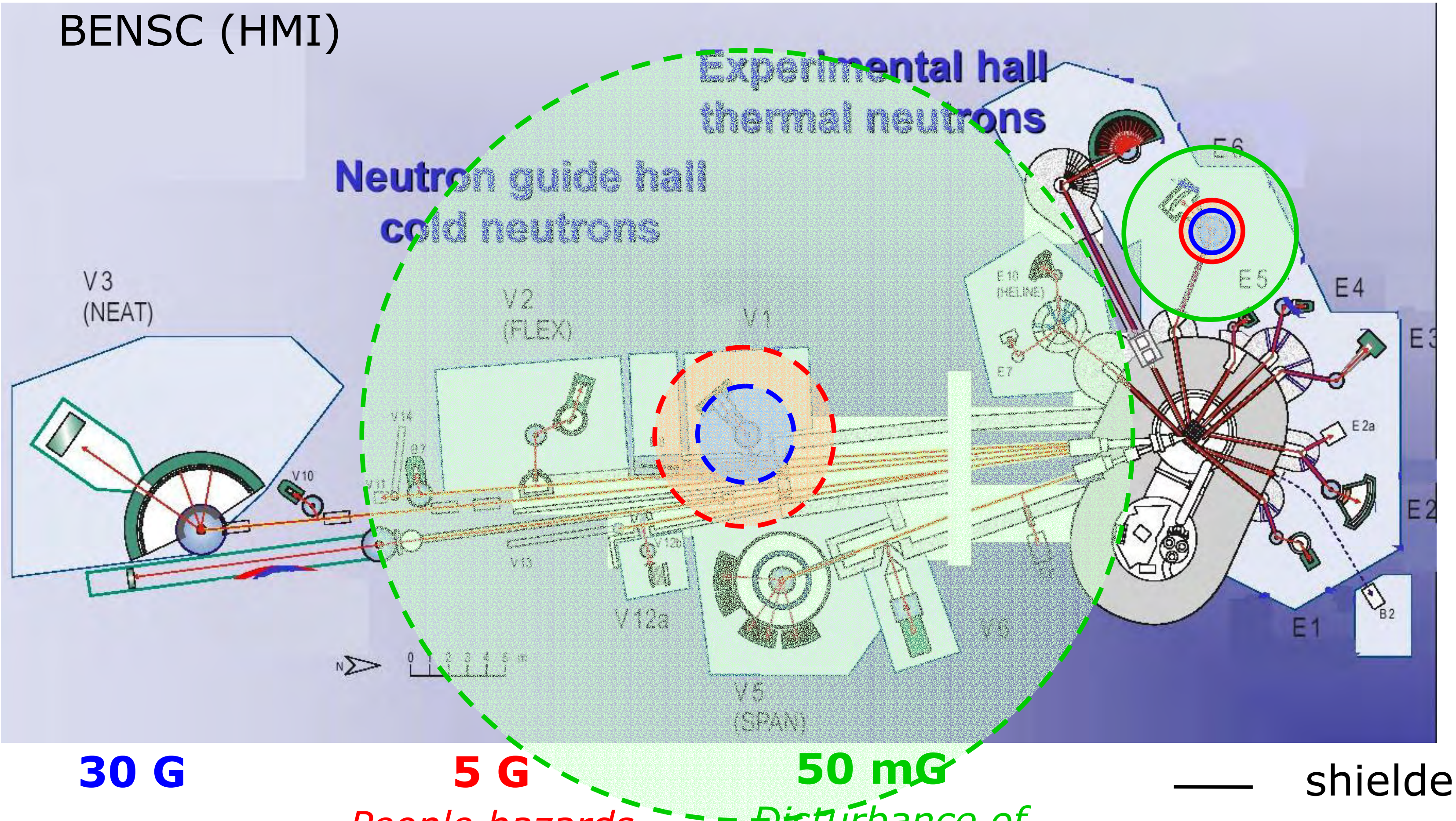
⇨ **Active shielding**:
multiple coil design with opposite polarity to compensate dipole moment



# Stray fields (shielded vs unshielded magnets)



# Stray Fields (shielded vs unshielded magnets)




**30 G**

*$He^3$ spin filters*

**5 G**

*People hazards, pacemakeres*

**50 mG**

*Disturbance of neighbouring instruments*

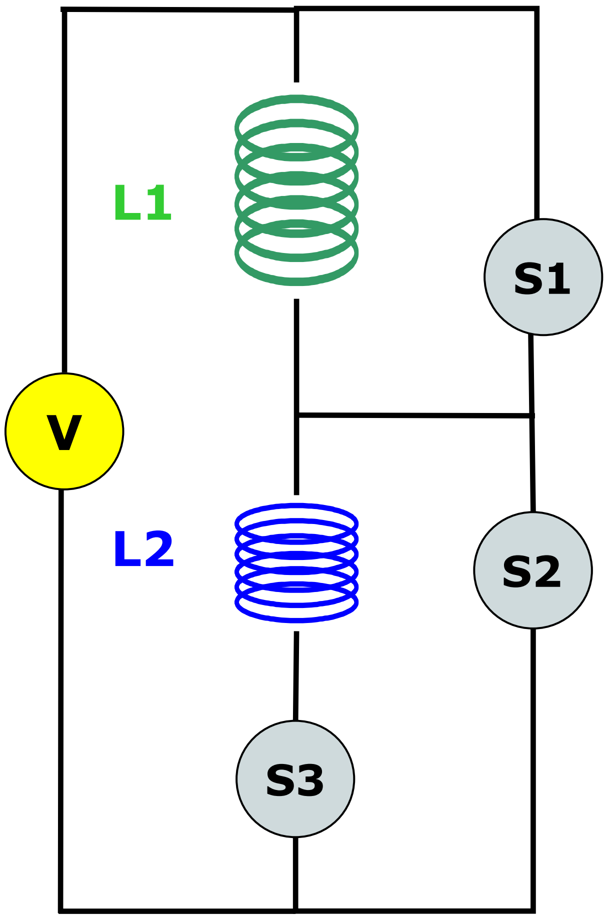
—— shielded

- - - - unshielded



Bruker BioSpin

# Symmetric and asymmetric mode operation



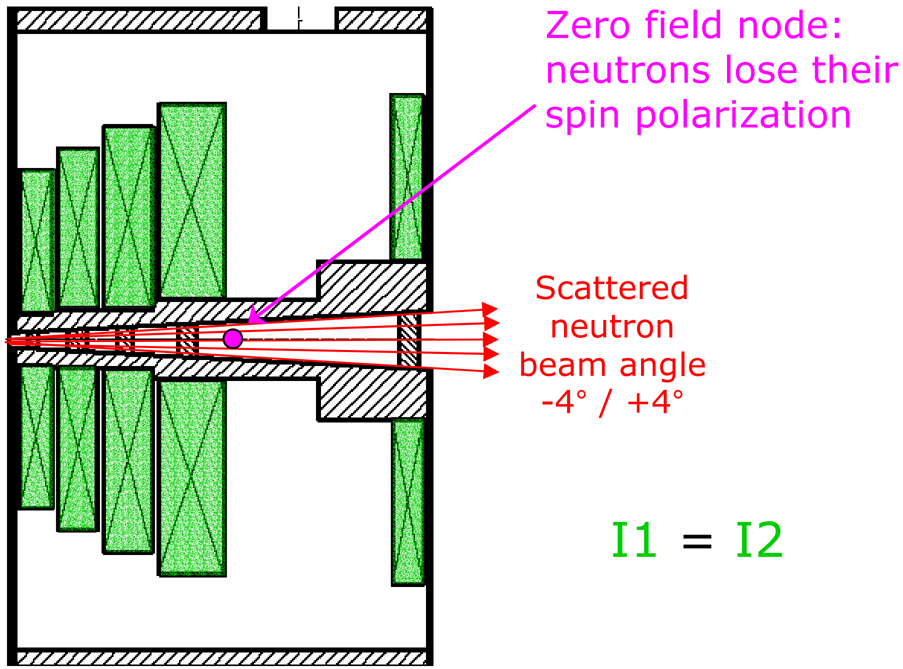

Two current loops L1 and L2 provide an adjustable asymmetric field distribution

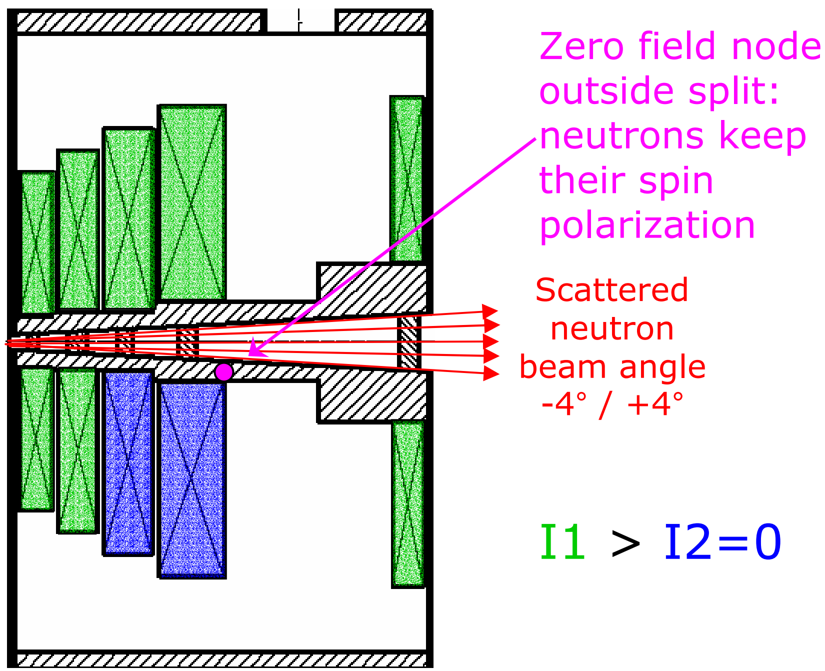
| | Switch S1 | Switch S2 | Switch S3 |
|---|---|---|---|
| Charging/discharging in symmetric mode | OPEN | OPEN | CLOSE |
| Charging/discharging in asymmetric mode | OPEN | CLOSE | OPEN |
| Persistent mode | CLOSE | CLOSE | CLOSE |

# Symmetric / Asymmetric mode operation

Symmetric mode operation
(up to 16 Tesla)

Asymmetric mode operation
(up to 14 Tesla)

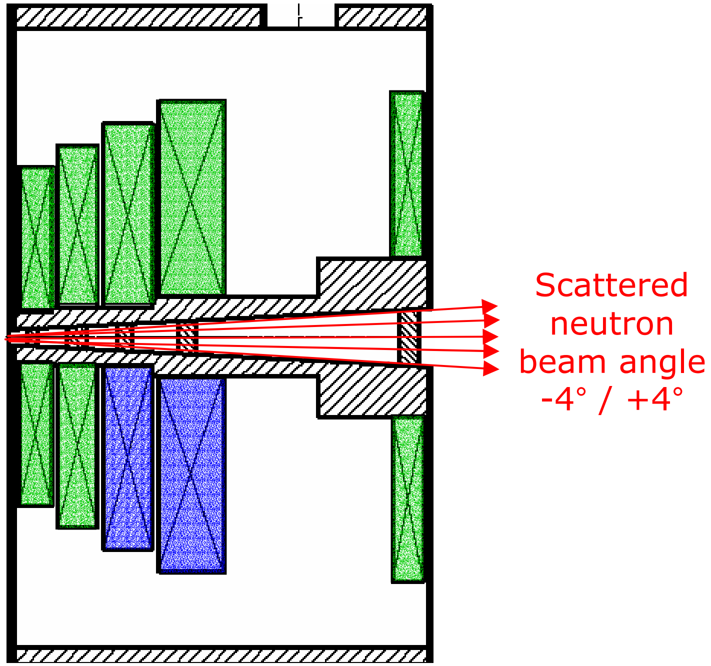


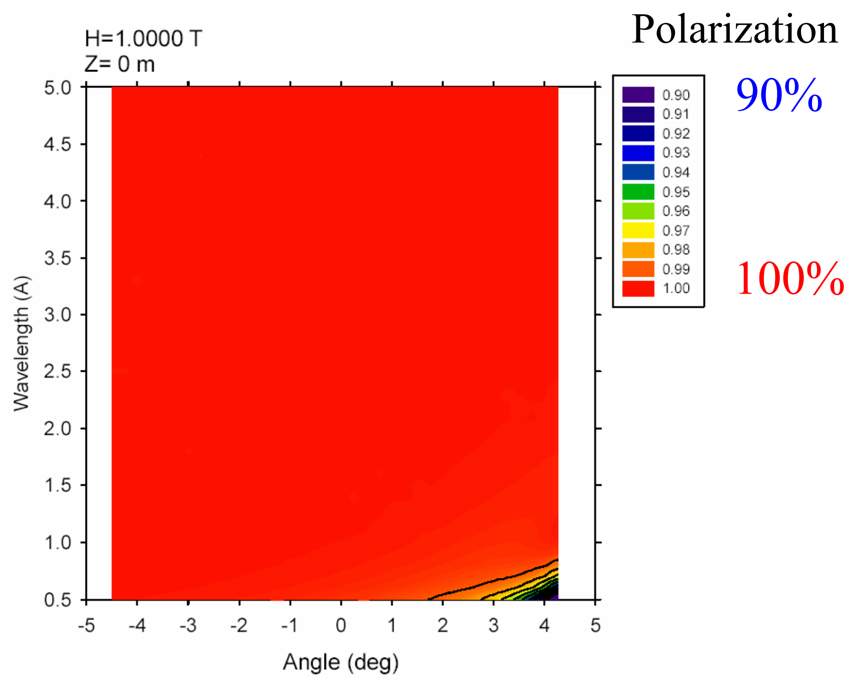
# Polarized Neutrons / Asymmetric mode operation

Asymmetric mode operation
(up to 14 Tesla)

Polarization > 97% for polarized neutrons with a wavelength > 0.5 Å (for initially perfectly polarized beam) at fields larger than 1 Tesla

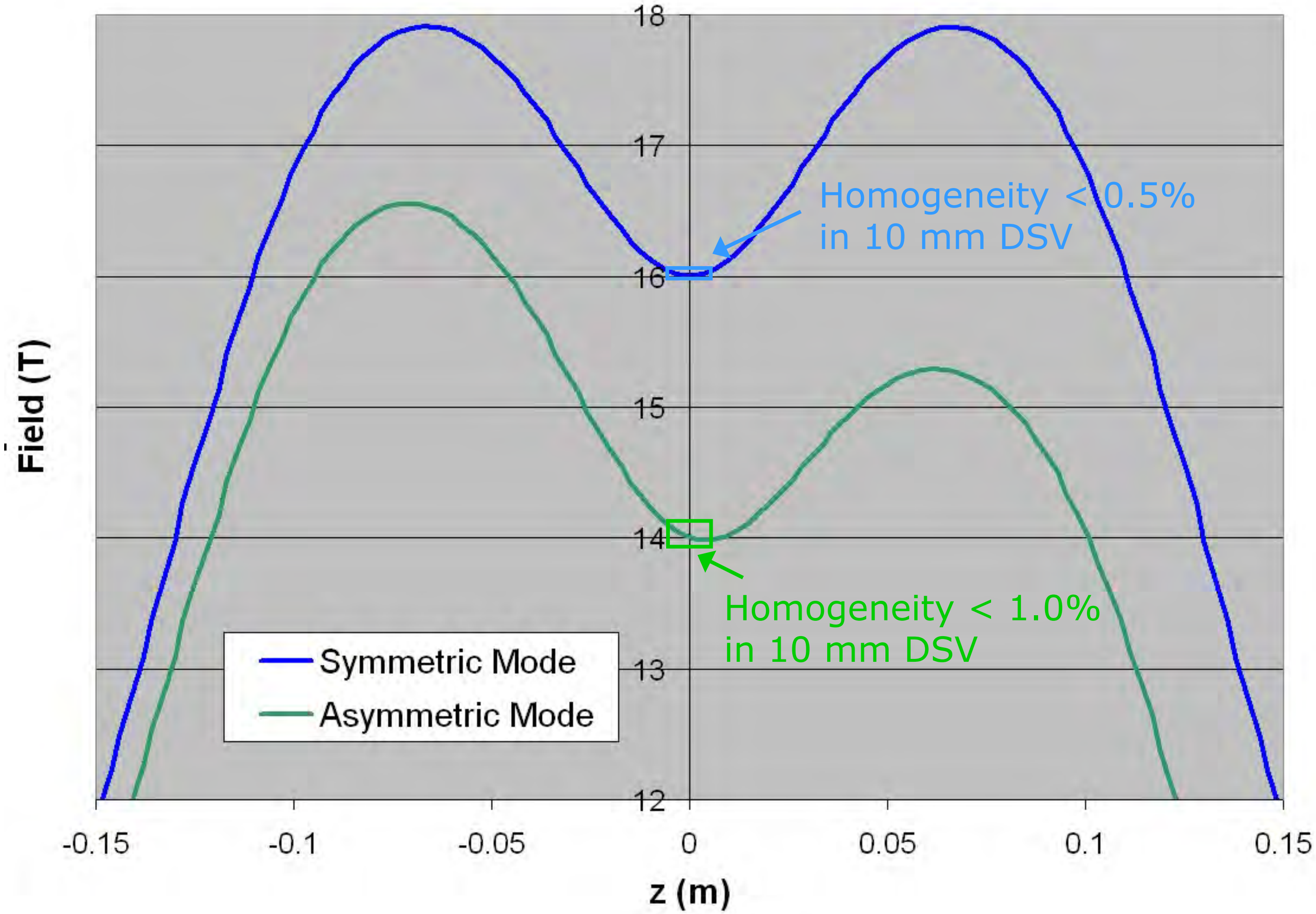



I1>I2=0

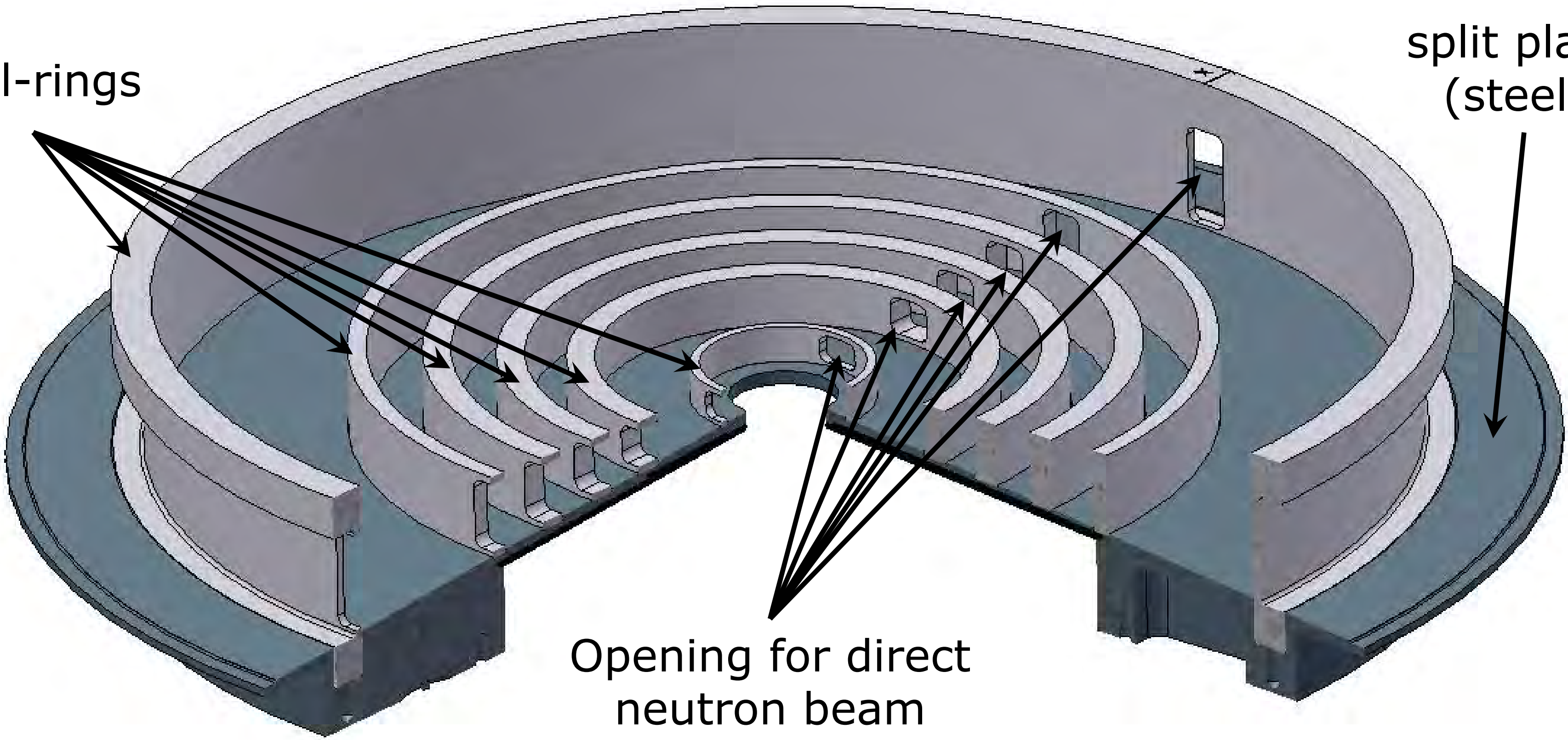



*Simulations performed by Wai Tung Hal Lee (ORNL) based on calculated field distribution in split.*

# On-axis field plot



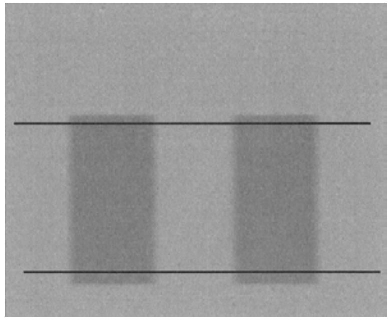
# Split region

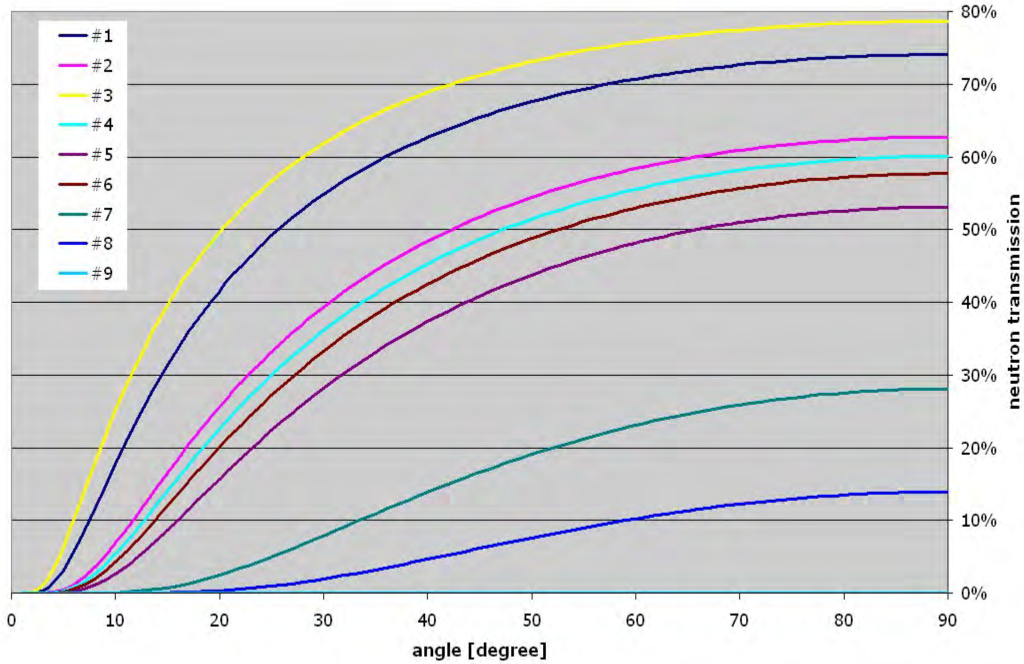


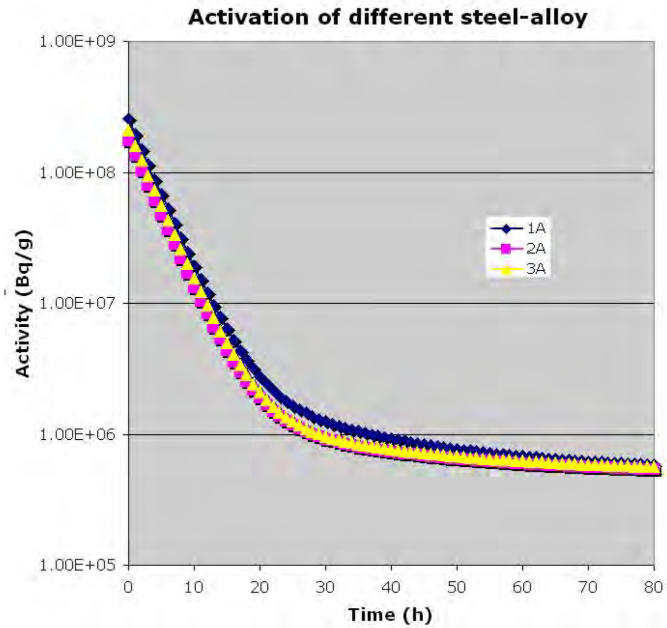
# Test of materials in neutron beam

Labor für Neutronenstreuung ETHZ & PSI

- absorption/scattering of different Al-alloys (transmission measurements)
- activation measurements of different Al- and steel-alloys (irradiation tests)
- absorption of neutron-absorbing coating for split-plate





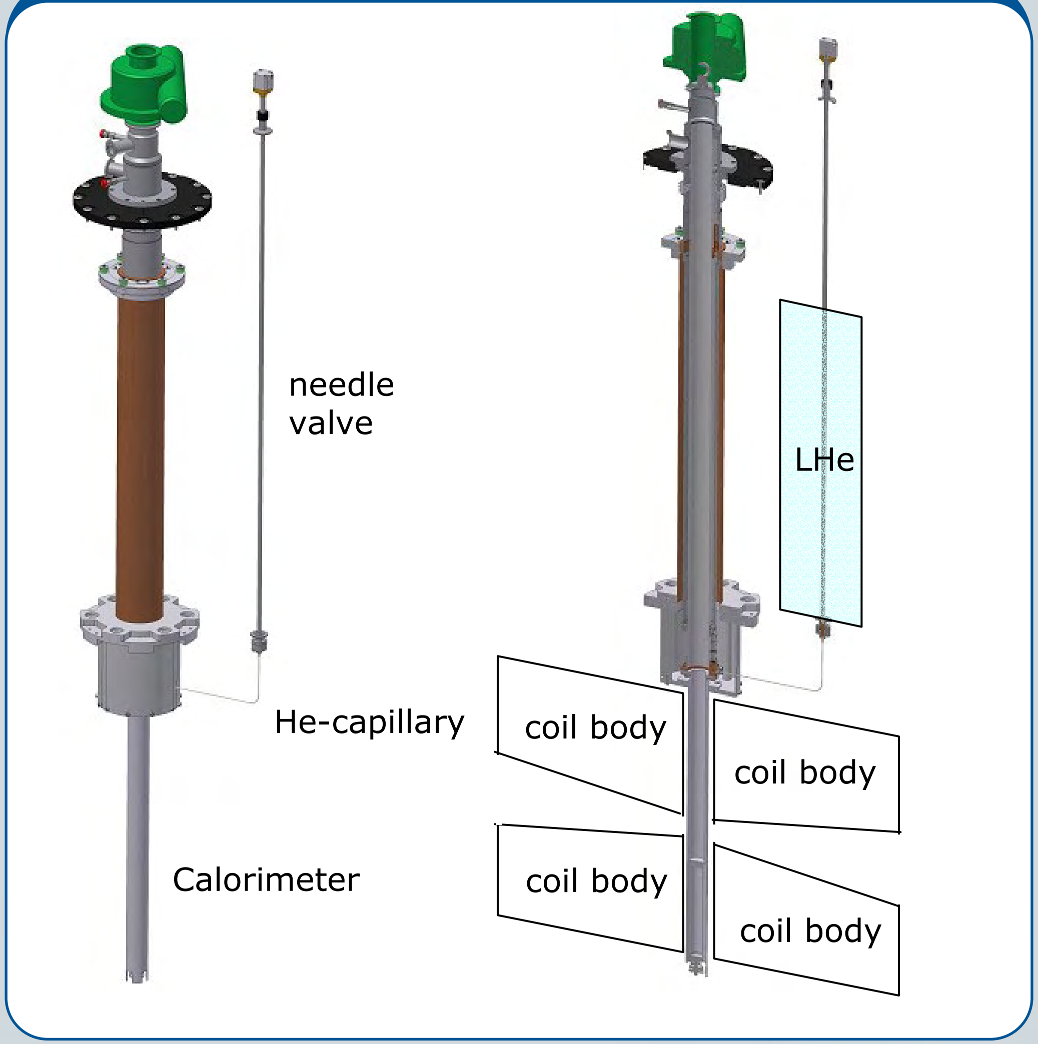



Bruker BioSpin

# VTI for 16 Tesla Split Coil Magnet System

Variable Temperature Insert (VTI) developed in close collaboration with ILL, Grenoble (France)

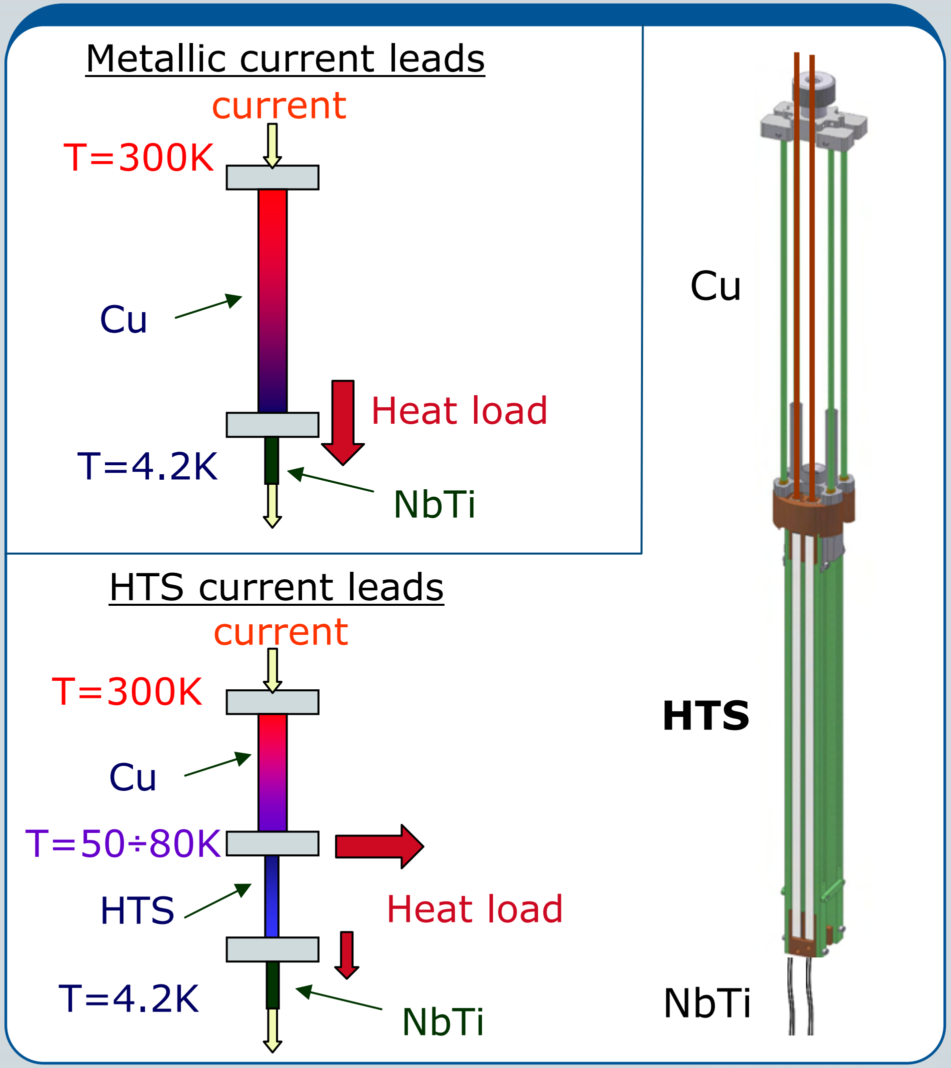
- **Main specifications**
  - 2-300 K in 34mm bore
  - Only pure Al in beam plane
  - Can accomodate dilution insert
  - Can accomodate furnace



# HTS current leads

- **Advantage of HTS current leads**
  - Heat load reduction
  - Long cryogenic hold time
  - Cooling cost reduction
  - Smaller cross sectional area

| LHe hold time at 4.2 K | |
|---|---|
| Specification | 4 days |
| *Metallic current leads* | *~ 4 days* |
| Low-loss HTS current leads | ~ 8 days |



# Timeline

- Feasibility has been checked
- Appropriate materials within the beam region have been identified
- Specifications of the magnet system have been defined

Contract has been signed in October 2006

Final system specification review took place in February 2007

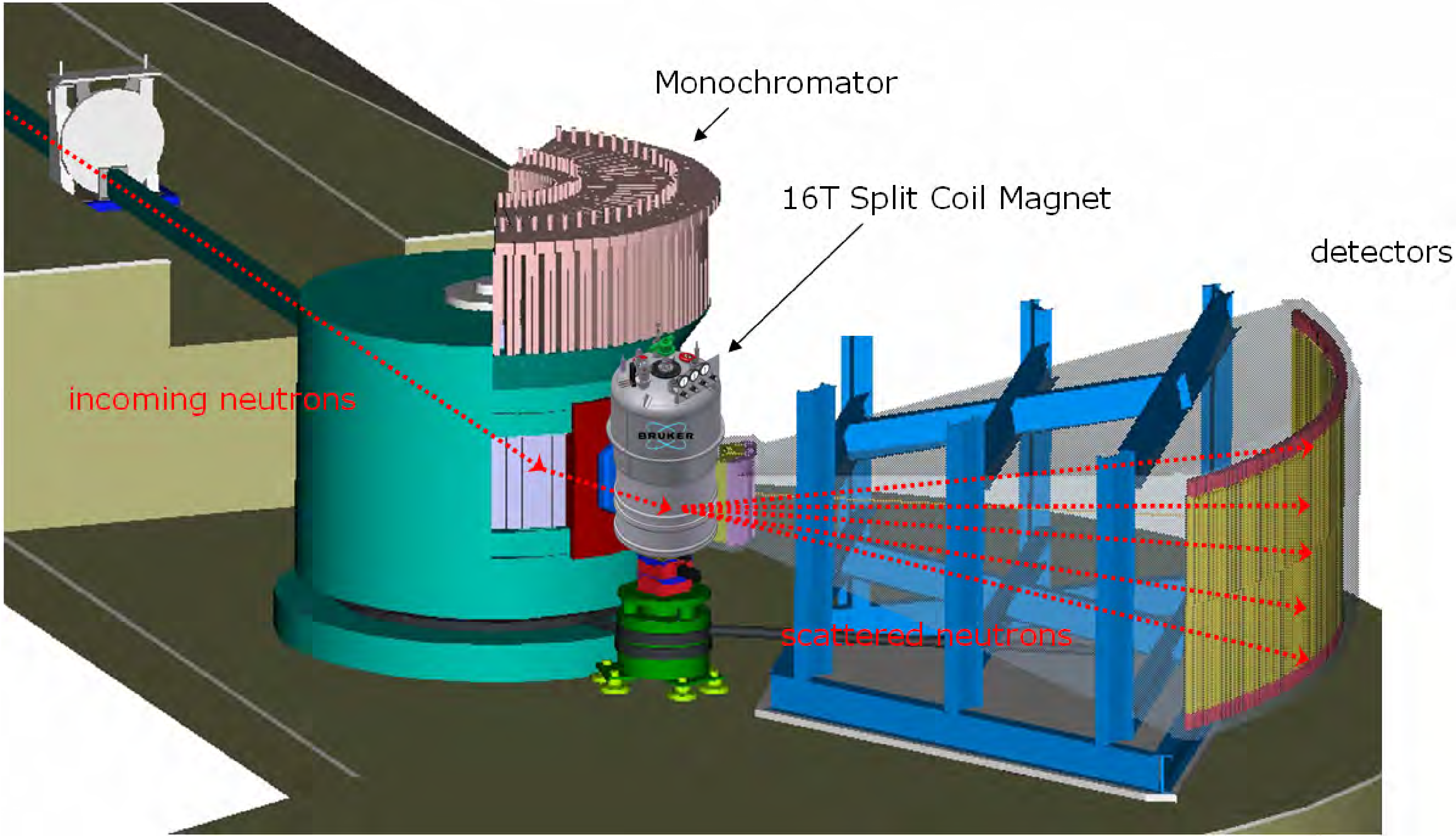
Design review took place in January 2008

1st quarter 2008 – 4th quarter 2008: construction of magnet system

1st quarter 2009 – 2nd quarter 2009: magnet tests at Bruker and at PSI

2nd quarter 2009: delivery to the Spallation Neutron Source (Oak Ridge, USA)

# High-field magnet at the HYSPEC (SNS)



# Acknowledgments

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SNS

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E. Lelievre
O. Losserand

*VTI*

BRUKER

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