
Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II)
Technische Universität München
JÜLICH
FORSCHUNGSZENTRUM
Jülich Centre for Neutron Science
GKSS
FORSCHUNGSZENTRUM
HELMHOLTZ ZENTRUM BERLIN
für Materialien und Energie
MAX-PLANCK-GESELLSCHAFT
Universität der Bundeswehr München
TU Clausthal
Excellence Cluster Universe
Physik Department
Institut und Lehrstuhl für Radiochemie
Klinikum rechts der Isar
Fakultät für Maschinenwesen
itm isotopen technologien münchen AG
itg isotope technologies Garching GmbH
flowmedical
LMU
RWTH AACHEN UNIVERSITY
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN
TECHNISCHE UNIVERSITÄT DRESDEN
TECHNISCHE UNIVERSITÄT DARMSTADT
Universität Augsburg
Universität zu Köln

Experimental facilities

Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II)

Contents

Preface		5
The neutron source FRM II		8
Secondary neutron sources		10
Neutron guides		12

Diffraction

RESI	thermal neutron single crystal diffractometer	16
HEIDI	single crystal diffractometer on hot source	18
POLI	polarized hot neutron diffractometer	20
SPODI	high resolution powder diffractometer	22
STRESS-SPEC	materials science diffractometer	24
BIODIFF	diffractometer for large unit cells	26
MIRA	multipurpose instrument	28

SANS and Reflectometry

KWS-1	small angle scattering diffractometer	32
KWS-2	small angle scattering diffractometer	34
KWS-3	very small angle scattering diffractometer	36
SANS-1	small angle neutron scattering	38
REFSANS	reflectometer and evanescent wave small angle neutron spectrometer	40
N-REX$^+$	neutron reflectometer with X-ray option	42
MARIA	magnetic reflectometer with high incident angle	44

Spectroscopy

PUMA	thermal three axes spectrometer	48
PANDA	cold three axes spectrometer	50
TRISP	three axes spin echo spectrometer	52
TOFTOF	cold neutron time-of-flight spectrometer	54
SPHERES	backscattering spectrometer	56
RESEDA	resonance spin echo spectrometer	58
J-NSE	neutron spin-echo spectrometer	60
DNS	diffuse scattering neutron time of flight spectrometer	62

Imaging

ANTARES	cold neutron radiography and tomography station	66
NECTAR	radiography and tomography using fission neutrons	68

Positrons

NEPOMUC	neutron induced positron source	72
CDBS	coincident Doppler-broadening spectrometer	74
PAES	positron annihilation induced Auger-electron spectrometer	75
PLEPS	pulsed low energy positron system	76
SPM	scanning positron microscope	77

Nuclear and Particle Physics

PGAA	prompt gamma activation analysis	80
MEPHISTO	facility for particle physics with cold neutrons	82

Irradiation facilities

Irradiation facilities		86

Sample Environment

SE	sample environment and user facilities	92
HT	high temperatures	94
LT	low temperatures	96
LT	low temperatures	98
HP	high pressure	100
MF	magnetic field	101

User office

General information for users	104
Access to the FRM II	106

Floor plan of the instruments — rear cover page

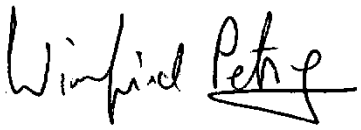
Dear user of the neutron source Heinz Maier-Leibnitz (FRM II).

Five years have passed since the first neutrons for scientific and industrial users were produced at the FRM II on May 2nd 2005. User operation started with 15 instruments, a number which has grown to the 27 presented in this brochure: all these instruments are either available or will be by the end of 2011 at the latest. In addition a second neutron guide hall has been constructed and this will be filled sequentially with additional instrumentation, the last expected to be completed in 2013.

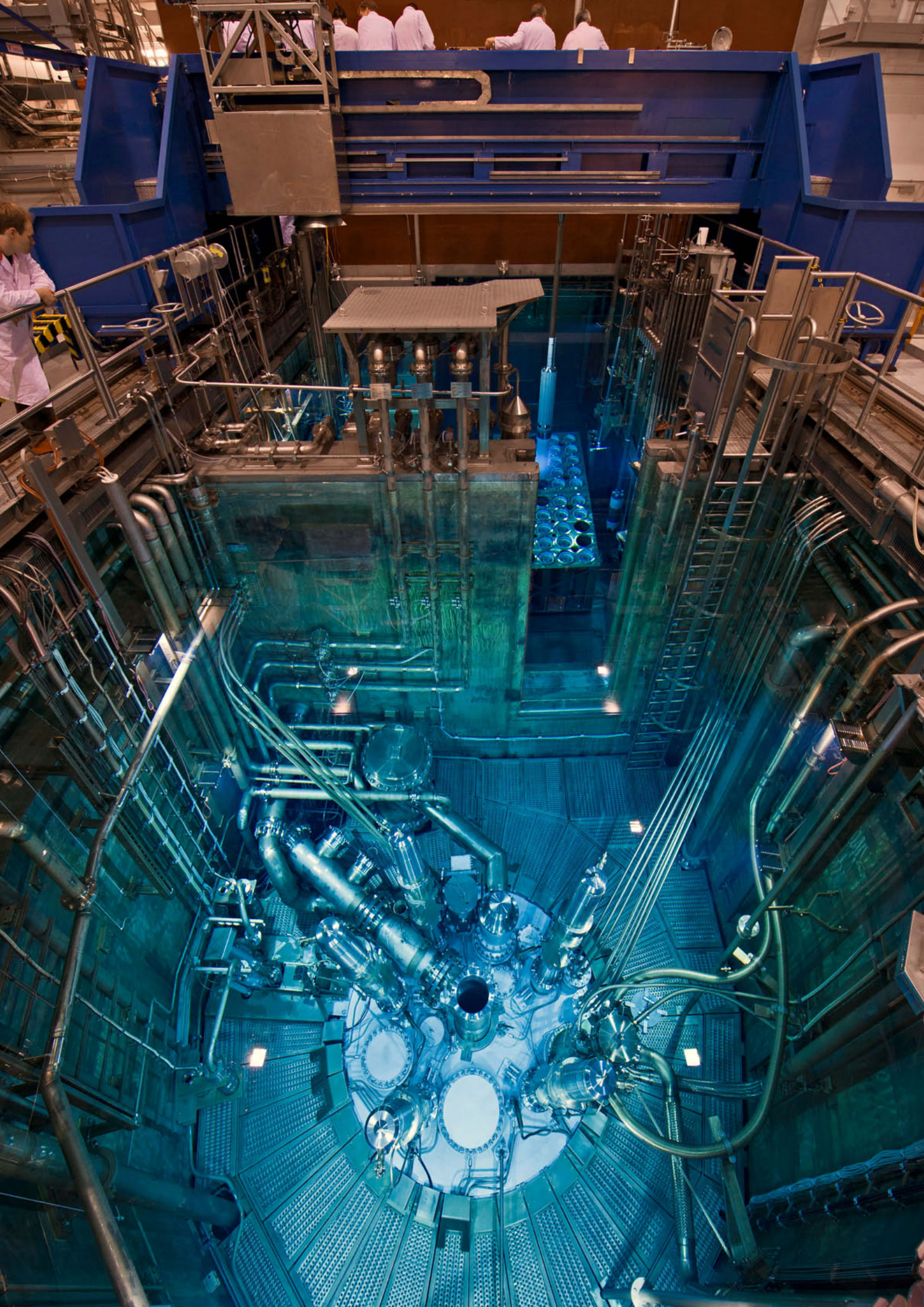
All this has only been possible as from the very beginning the scientific usage of the FRM II has been a collaborative undertaking. Altogether 10 universities, three national laboratories from the Helmholtz Association and last but not least the Max Planck Society are engaged in the development of innovative neutron methodology, to build first class instrumentation and to operate those to the benefit of the national and international scientific community. The Forschungszentrum Jülich with its outstation the Jülich Centre for Neutron Sciences (JCNS) at the FRM II is certainly the most important partner in this joint task. The Technische Universität München greatly appreciates the enormous personal and financial engagement of these institutions at FRM II, in particular the continuous funding of the university projects by the German Ministry of Science (BMBF). Credit to all these partners is given on the bottom line of each instrument presented in this brochure.

This brochure is intended to give our international users the information they need to successfully apply for beam time at our facility. I hope you enjoy learning about the exciting experimental possibilities at the FRM II.

Yours

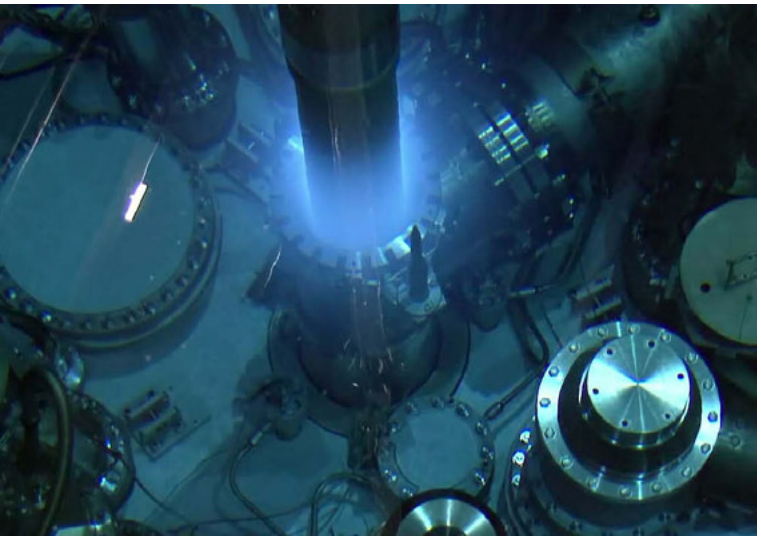


Prof. Dr. Winfried Petry
Scientific Director
Forschungs-Neutronenquelle
Heinz Maier-Leibnitz (FRM II)



Neutron Source

The neutron source FRM II



Powerful neutron source

The neutron source Heinz Maier-Leibnitz (FRM II) is a beam tube reactor designed for providing neutrons to scientific experiments from all over the world as well as for medical and industrial applications. The FRM II is operated as a central scientific institution by the Technische Universität München (TUM) in Garching near Munich, Germany. Its first criticality was reached in March 2004.

The FRM II is the most powerful neutron source in Germany and reaches the highest neutron flux ($8 \cdot 10^{14}$ neutrons/cm^2 s) relative to its thermal power (20 MW) throughout the world. More than 30 experimental facilities will be operated by scientific teams from German universities, research institutes of the Helmholtz Association and the Max-Planck-Society at the neutron source. Today, 23 of these facilities are operational. Further 7 irradiation facilities mainly for medical purposes are in service, an irradiation facility for the production of the medical isotop ^{99}Mo is under construction. The FRM II is equipped with cold, thermal, hot and even fast fission neutron sources and thus covers a broad range of applications, including experiments with positrons.

Fuel element

The FRM II has been designed for an exclusive purpose: the production of neutron beams. Its high performance is based on the concept of a compact core: a single, cylindrical fuel element with a diameter of just 24 centimetres is sufficient for 60 days of reactor operation. The fuel zone measures 70 centimetres and contains 8 kilograms of uranium in the form of U_3Si_2. Like other high-performance neutron sources around the world, the FRM II uses highly enriched uranium. This leads to a high neutron flux

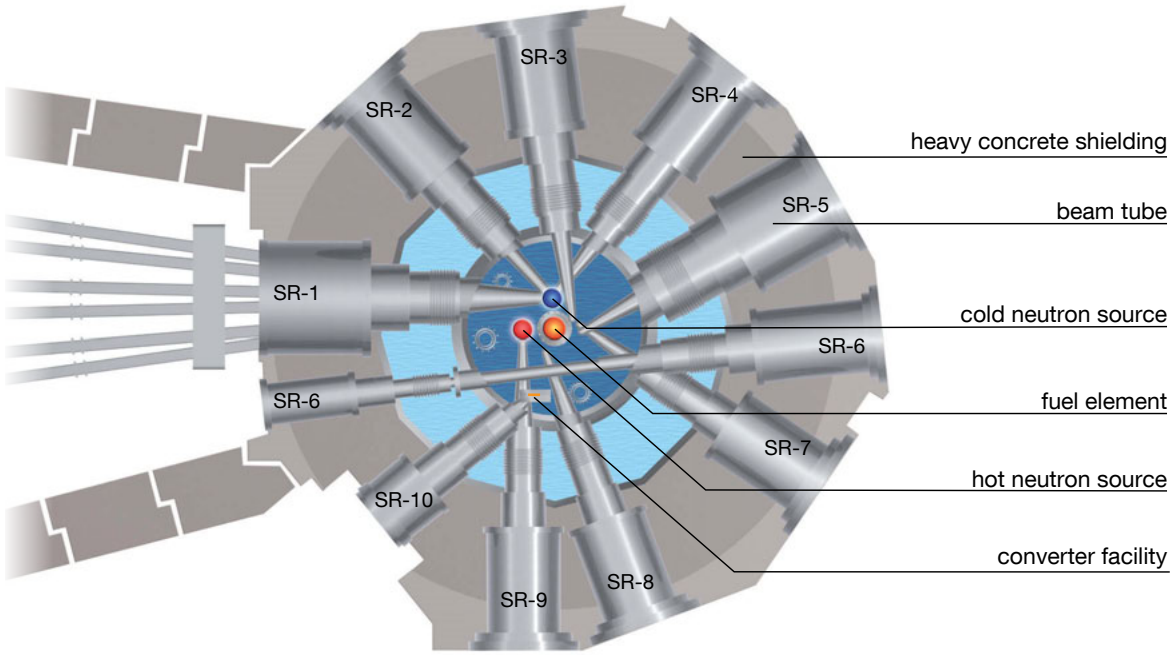


Figure 1: Horizontal section of the reactor pool showing the beam tubes, fuel element, as well as cold and hot neutron source. Beam tube 1, 2 and 4 are fed by the cold source, number 9 by the hot source. The through-going beam tube no. 6 will be used by the ultra cold neutron source. The converter plate for fast neutrons supplies beam tube no. 10 with the tumour treatment facility. The remaining beam tubes are placed into the highest neutron flux taking up the thermal neutrons.

producing a minimal amount of radioactive waste. The fuel element is located in the centre of a moderator tank filled with heavy water (D_2O). The tips of the beam tubes are placed in the region of the maximum thermal neutron flux density. Various vertical irradiation channels are arranged in the moderator tank. The beam tubes guide the neutrons to the experiments in the experimental hall and neutron guide hall west.
The experimental hall provides high neutron flux and access to the positron beam lines, whereas the neutron guide hall west is connected via six neutron guides to the cold neutron source. A second guide hall will be connected to the reactor building soon in order to extend the number of available instruments.

Safety first

The highest priority is always given to safety at the FRM II. The inherent safety stems from its principle design, with a compact fuel element built into the centre of the moderator tank filled with heavy water. Fuel element, moderator tank and beam tubes are built into the reactor basin filled with 700 cubic metres of highly purified water. While passing the fuel element, the temperature of the cooling water only increases from 36 to a maximum of about 51 degrees Celsius. Neither steam nor high pressures are produced. Three subsequent cooling circuits guarantee the safe dissipation of the 20 MW.
Redundant safety installations (i.e. multiple, independently constructed units) are a key feature of the safety concept of the FRM II. The central control rod inside the fuel element, for example, is used to regulate and shut down the reactor. Additionally, a redundant set of five shut-down rods is available. Each of these systems is constructed such that the reactor can be shut down in a fast and durable manner, completely independently.
The 1.8 metre thick outer concrete wall of the reactor building protects the reactor against all impacts from outside. It has been designed to resist the crash of a fast military jet as well as the crash of a passenger aircraft. This has been approved by independent experts. Furthermore, the building

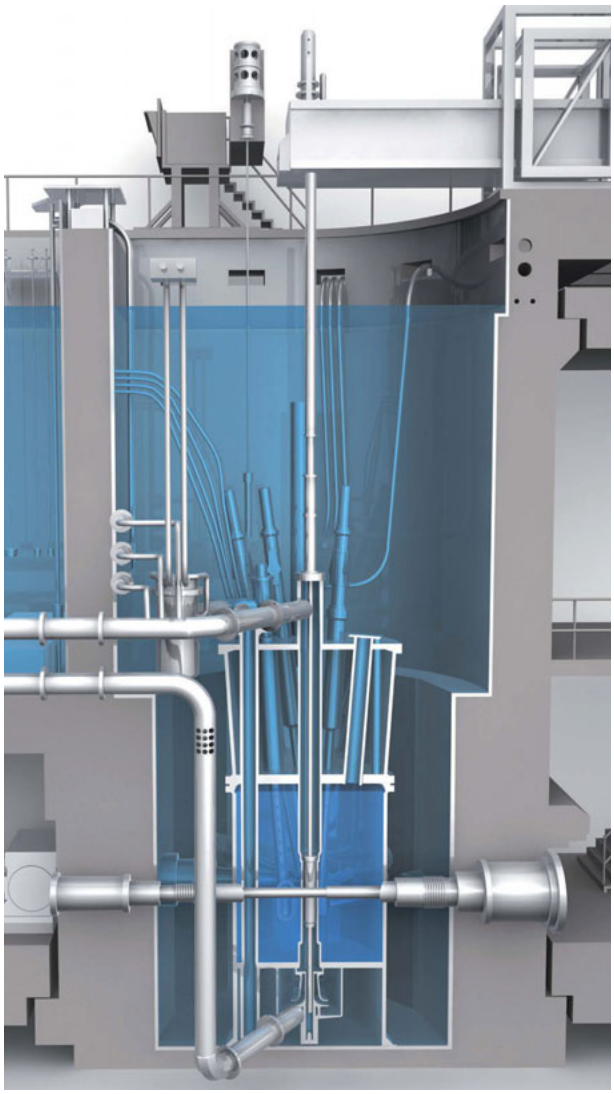


Figure 2: Vertical section of the reactor pool of the FRM II filled with water. The moderator tank, cooling circuit, safety facilities as well as the secondary sources are depicted.

can withstand earthquakes up to 5.8 on the Richter scale, which is beyond the strength of possible earthquakes in the region, or a high floodwater from the nearby river Isar with a height, that might occur once every 10,000 years.

Technical Data

Reactor main parameters

- 20 Megawatt thermal power
- $8 \cdot 10^{14}$ neutrons/cm^2 s max. undisturbed flux
- 10 horizontal; 2 tilted beam tubes
- D_2O moderator
- H_2O cooling water

People and money

- 435 million € construction cost
- ~300 employees on site

Instruments

- 21 instruments in routine operation (2010)
- 9 instruments under construction

Fuel element

- Dimensions:
  133 cm height; 24 cm outer diameter,
  70 cm active zone
- 8 kg U_3Si_2 in 113 fuel plates
- 60 days / fuel element - typical 240 days of operation per year

Technical Director Dr. Anton Kastenmüller

Phone: +49.(0)89.289.12154
Email: anton.kastenmueller@frm2.tum.de

Secondary neutron sources

The different instruments at the neutron source FRM II are supplied by various secondary sources slowing down or speeding up the neutrons after exiting the fuel element. This enables a large variety of applications. Furthermore beam tube SR11 hosts the positron source NEPOMUC, which is decribed in the chapter Positrons.

The cold source

At the FRM II, half of the experiments are performed using cold neutrons. The beam tubes no. 1, 2 and 4 are supplied with cold neutrons. The cold neutron source is located only 8 centimetres distance from the fuel element close to the maximum thermal neutron flux. It shifts the thermal neutron energy spectrum to lower energies. The close vicinity to the core results in a broad spectrum of the cold source (see fig. 3).
The cold source consists of several parts. A vessel with a liquid deuterium moderator is located in the moderator tank. Its volume adds up to 25 litres and it contains about 12 litres of liquid deuterium at 25 K. A helium refrigerator cools down the liquid deuterium, which heats to its boiling point at 25 K by gamma radiation and neutron moderation. The liquid deuterium is kept at 25 K and 1.5 bar at full reactor power in order to moderate the thermal neutrons.
The vessel containing the liquid deuterium is linked with the D_2-He heat exchanger in the reactor pool. The heat exchanger recondenses the vaporized deuterium and lets it drop back to the vessel. Natural convection drives the circuit of deuterium. Both parts of the cold source, the vessel and the heat exchanger, are called the inpile section. The helium-deuterium heat exchanger itself is cooled by an outside helium-refrigerator. A buffer tank and a metal hydride storage tank, located outside the reactor building, store the deuterium gas and are linked to the heat exchanger. Preparing the cold neutron source for operation takes about one week.

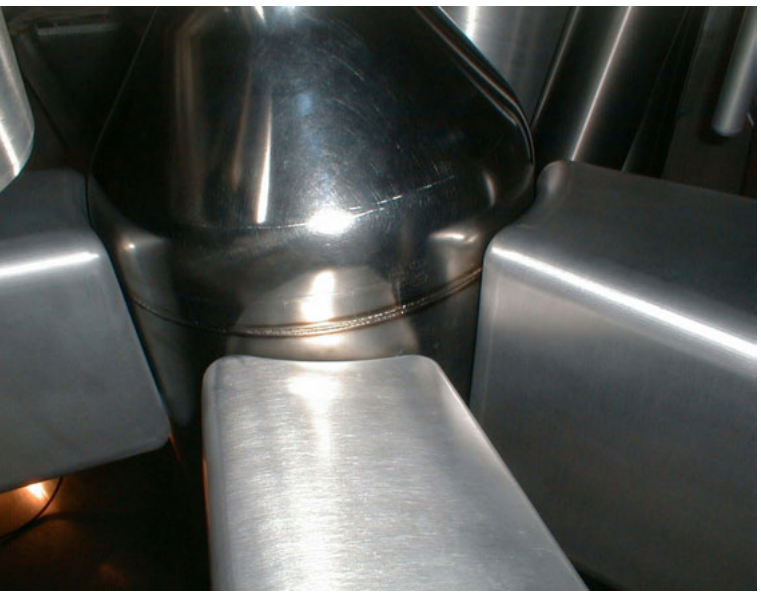


Figure 1: The cold source vessel surrounded by the beam tubes SR 1, 2, 4. View into the modarator tank of the FRM II before operation.

The energy distribution of the neutrons generated by the cold source shown in figure 3 has its maximum at 1.4 Å (40 meV), thereby extending the usable range of incident energies for cold neutron instruments towards higher energies. The average neutron flux density in the cold source is about $3 \cdot 10^{14}$ neutrons/cm^2 s at full reactor power, resulting in a cold neutron flux density of $9.1 \cdot 10^{13}$ neutrons/cm^2 s.

The hot source

Neutrons of short wavelengths in the range of 0.1 eV to 1 eV are used to investigate the structure of condensed matter. As only a small fraction of this spectral range is present in the thermal neutron

Figure 2: The moderator of the hot source in the reactor pool of the FRM II during installation.

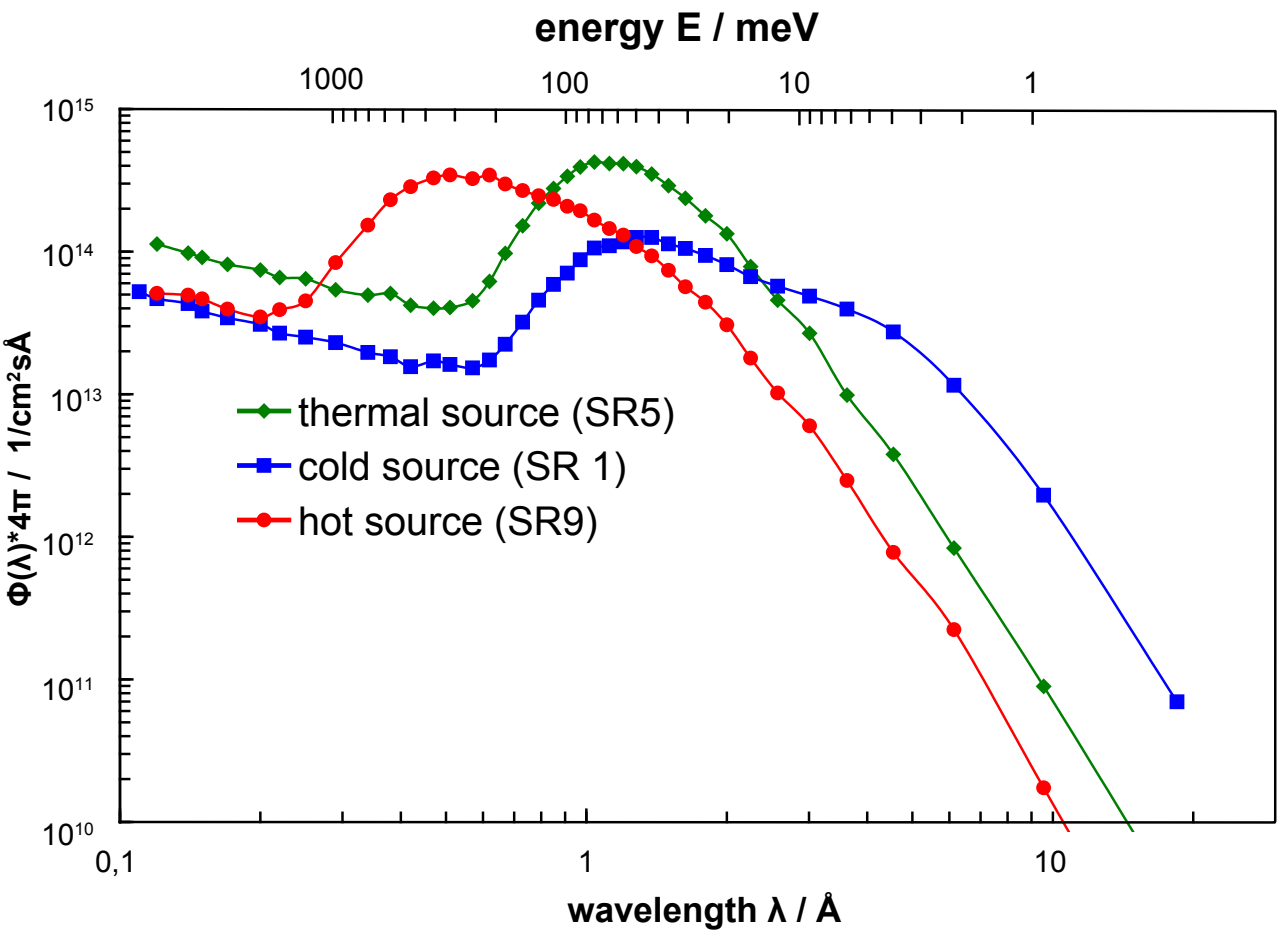


Figure 3: Neutron spectra at the entrance of the beam tubes at 20 MW reactor power.

distribution, the neutrons are moderated upwards from 309 K to 2273 K. This spectrum shift is performed by the hot neutron source.
The hot moderator consists of a graphite block thermally insulated and positioned in the moderator tank next to the maximum thermal neutron flux. The graphite cylinder is heated by gamma radiation and by neutron radiation from the reactor. The heat is released into the surrounding moderator tank. A double-wall zircaloy container with interposed insulating graphite felt insulates the graphite block, ensuring a secure containment of the hot graphite. At a reactor power of 20 MW the temperature inside the container rises to about 2000 °C. The hot source provides neutrons to beam tube no. 9, which supplies the single crystal diffractometers HEiDi and Poli-HEiDi.

Technical Data

Cold source

- T = 25 K
- Volume of moderator vessel: 25 l
- Mass of D_2 in cold source: 2.4 kg
- Cold moderator pressure: 1.5 bar
- 18 instruments fed by cold source

Hot source

- Mass of graphite in hot source: 14 kg
- Temperature at 20 MW reactor power: 2000° C

Converter facility for fast neutrons

In order to obtain a high-intensity neutron beam with an unmoderated fission spectrum, an arrangement of uranium plates is inserted as a converter in front of the tip of beam tube no. 10. It supplies the tumour treatment facility MEDAPP and the radiography and tomography station NECTAR with fast neutrons. Slow neutrons induce nuclear fission in the uranium plates causing the emission of neutrons with an energy of 1.9 MeV. The fast neutrons are led without moderation through a horizontal beam tube to the experiments. The two converter plates deliver a thermal power of about 80 kW.

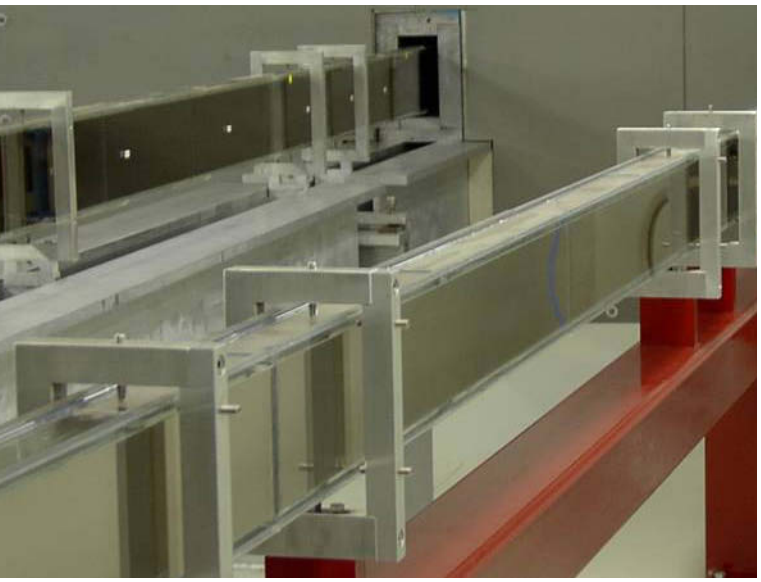
Converter facility

- Mass of uranium in converter plates: 540 g
- Thermal power 80 kW

Technical Director Dr. Anton Kastenmüller

Phone: +49.(0)89.289.12154
Email: anton.kastenmueller@frm2.tum.de

Neutron guides



The FRM II makes extensive use of modern neutron guides to transport and distribute the neutrons over large distances in the experimental hall (SR 2, 5, 8) as well as in the neutron guide halls. Adapted to the needs of the instruments with respect to wavelength distribution and angular dispersion the guide elements are coated by ^{58}Ni or supermirror coatings with m values up to 3.0; on focussing sections up to m=3.6.

Cold neutron guides

Beam tube SR1 facing the cold neutron source delivers the neutron beams for the entire Neutron Guide Hall West. The In-pile unit of SR1 consists of a mirror box with m=2.2 supermirror coating on Al-plates and a dividing section of 2.1m length, where the beam is divided into the 6 principal neutron guides. Figure 1 shows schematically how the neutron guides are further split in order to serve a maximum number of instruments, especially with end standing positions.
Besides SR1 the cold neutron three axes spectrometer PANDA on beam tube SR2 also has supermirror inserts in the in-pile section of the primary beam. In the near future SR4b will be equipped with a neutron guide for the nuclear and particle physics beam line MEPHISTO in the Guide Hall East. Right now almost 500 m of cold neutron guides are already installed.

Thermal neutron guides

Beam tubes SR8a and SR8b are equipped with supermirror guides with coatings up to m = 3. At SR5b a polarizing supermirror bender provides the instrument TRISP with polarized neutrons. In total roughly 50m of thermal guides are installed. In the near future elliptical focussing thermal guides will provide neutron beams for the instruments in the Guide Hall East.

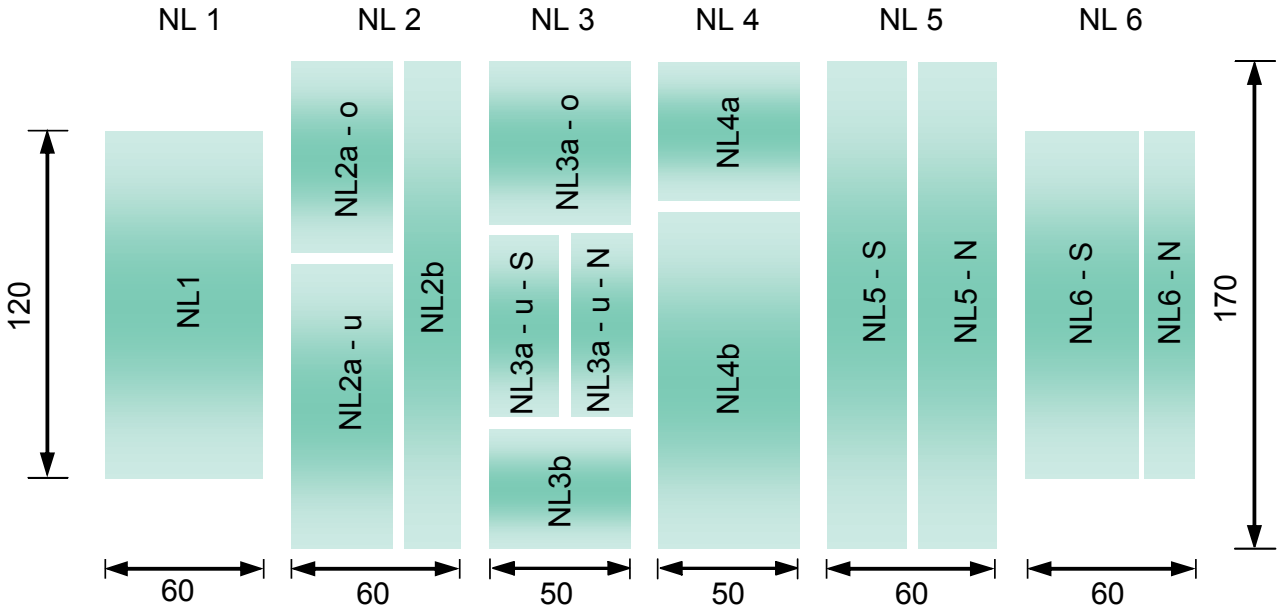


Figure 1: The sectioning of the 6 principal neutron guides of SR1. The subsections are referred to by the letters a, b, u, o, S, N.

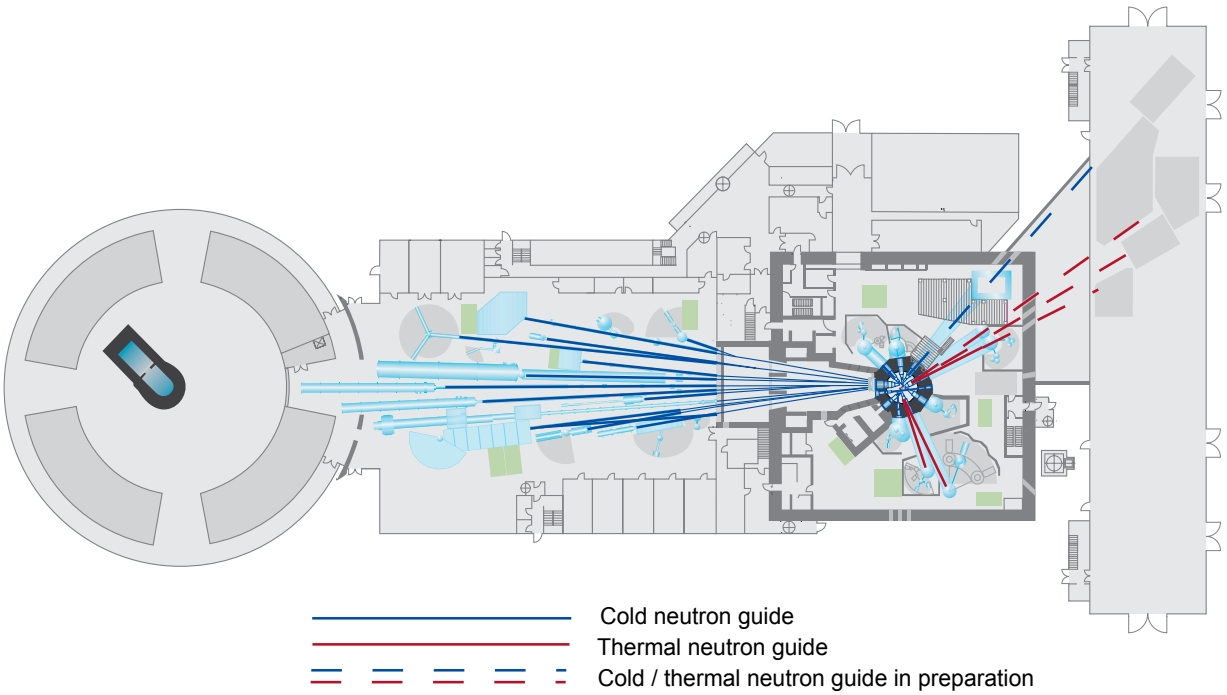


Figure 2: Floorplan of the FRM II with the neutron guide system.

Technical Data

Guide	NL1	NL2a-o	NL2a-u	NL2b
Length (m)	40	48	60	57
Section (mm²)	60 × 120	44 × 60	44× 100	12 × 170
Coating up to	m = 2.5	m = 3.0	m = 2.0	m = 2.0
Radius (m)	1000	2000	160	400
Instruments	BIODIFF NREX⁺	J-NSE	TOFTOF	REF-SANS

Guide	NL3a-o	NL3a-uS	NL3a-uN	NL3b
Length (m)	46	30	29	51
Section (mm²)	50 × 50	10 × 56	38 × 56	50 × 45
Coating up to	m = 3.0	m = 3.0	m = 3.0	m = 2.0
Radius (m)	460	30	460	1500
Instruments	KWS-2	KWS-3	unused	KWS-1

Guide	NL4a	NL4b	NL5-S
Length (m)	34	52	70
Section (mm²)	50 × 50	50 × 110	29 × 170
Coating up to	m = 2.0	m = 3.0	m = 2.0
Radius (m)	2100	390	1640
Instruments	SANS-1	PGAA	RESEDA TREFF

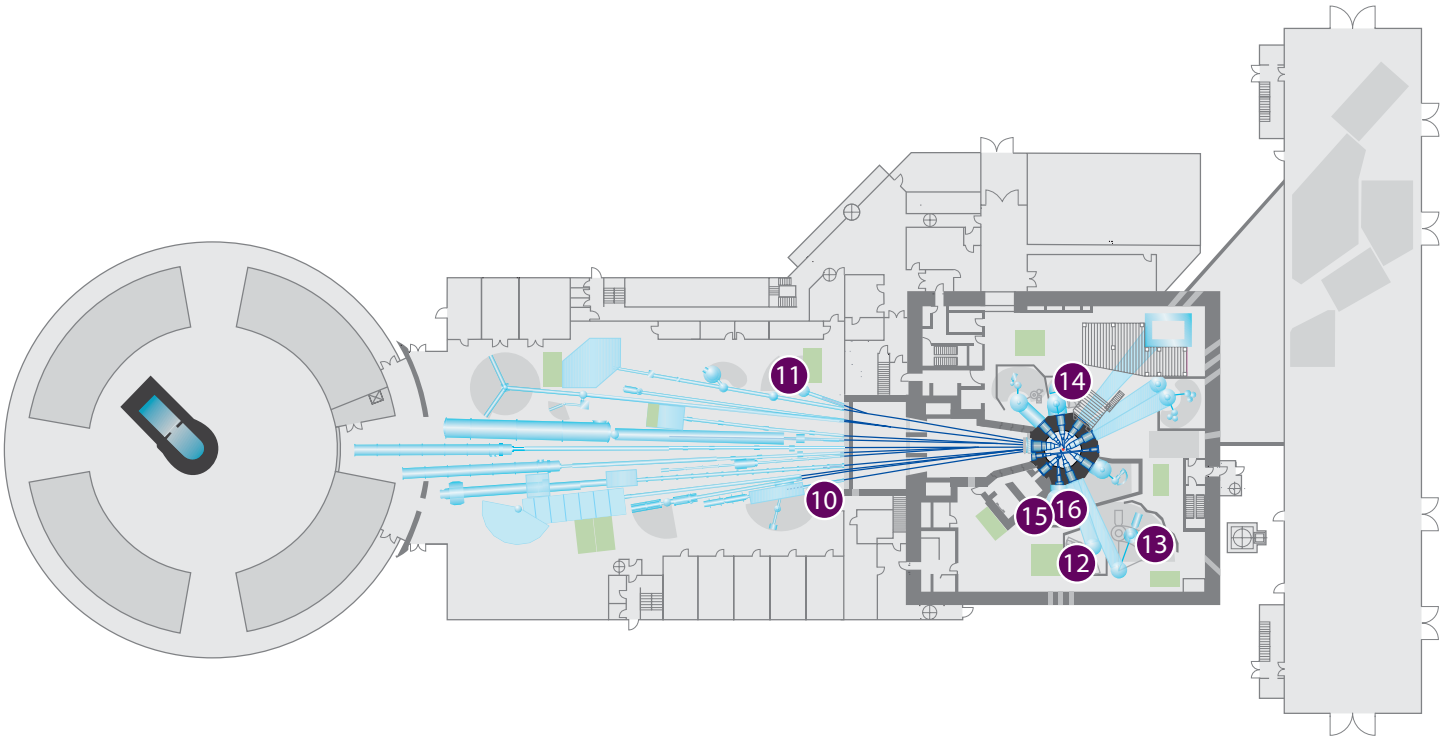
Figure 3: Neutron guides inside the neutron guide tunnel.

Guide	NL5-N	NL6-S	NL6-N
Length (m)	35	54	35
Section (mm²)	29 × 170	60 × 120	10 × 120
Coating up to	m = 2.0	m = 2.2	m = 2.0
Radius (m)	400	1000	84
Instruments	MARIA	MIRA-2, DNS SPHERES	MIRA

Prof. Dr. Gunther Borchert

Phone: +49.(0)89.289.14629
Email: gunther.borchert@frm2.tum.de

www.frm2.tum.de/n-optics



10

BIODIFF
diffractometer
for large unit-cells
p. 26 / 27

11

MIRA
cold neutron
mulitpurpose instrument
p. 28 / 29

12

RESI
single-crystal diffractometer
on thermal beam
p. 16 / 17

13

SPODI
neutron powder diffractometer
p. 22 / 23

14

STRESS-SPEC
materials science
diffractometer
p. 24 / 25

15

HEIDI
single-crystal diffractometer
with hot neutrons
p. 18 / 19

16

POLI
polarized neutron
diffractometer
p. 20 / 21

Diffraction

RESI

thermal neutron single crystal diffractometer

Description

The diffractometer RESI is designed for using a maximum of thermal neutron intensity at the FRM II, allowing optimum measurement of weak diffraction phenomena in a large portion of the reciprocal space on single crystalline samples.

Typical Applications

Structure analysis with thermal neutrons (λ = 0.8 Å to 2 Å) is complementary to structure analysis with X-rays. The measurement possibilities provided by this instrument are crucial for many scientific questions:

- **Structure analysis, bonding theory, electron densities:** Due to the interaction with atomic cores and the diffraction angle independence of the atomic form factor, it is possible to measure Bragg scattering up to high diffraction angles.
- **Real crystals** and compounds of interest for material science are often not perfectly ordered. The elucidation of these real structures requires the analysis of the corresponding diffuse scattering. The diffuse scattering - off the Bragg reflections - is normally differentially weak and distributed continually (anisotropic) in the reciprocal space.
- **Partially crystalline** compounds, like **fibre structures**, show a specific scattering, which is highly anisotropic and continously distributed in the reciprocal space. Therefore, diffractometers with area detectors like RESI are best suited for this kind of problems.
- A new class of **aperiodic crystals** (“quasi crystals”) show dense, but discrete reflex patterns, where more than 90 % of the reflexes are very weak. Additionally, due to the fact that quasi crystals often contain two or more transition metals (which are almost isoelectronic), neutrons offer much higher contrast than X-ray methods.
- **Structural phase transitions** can be accompanied by continuous reflection shifting.
- **Modulated structures** show satellite reflections at “incommensurable” positions. Both areas require analysis of large portions of the reciprocal space.
- **Twinned crystals** and **multi-domain/multi-phase crystals** are often difficult to measure on single-counter instruments. The area detector at RESI allows for easy detection and in many cases separation of reflections in such systems.

The advantages of the high-resolution area detector can be utilized best, if the reciprocal space is not too empty. That means, that RESI is optimal for cells of ca. 1000 Å^3 to ca. 20000 Å^3. Typical crystal sizes range from 5 mm^3 to 25 mm^3.

Sample Environment

Dedicated sample environment of RESI:

- Oxford Cryosystems Cryostream 700
  temperature range 100 K - 400 K
  consumption ~ 20 l L-N_2/d

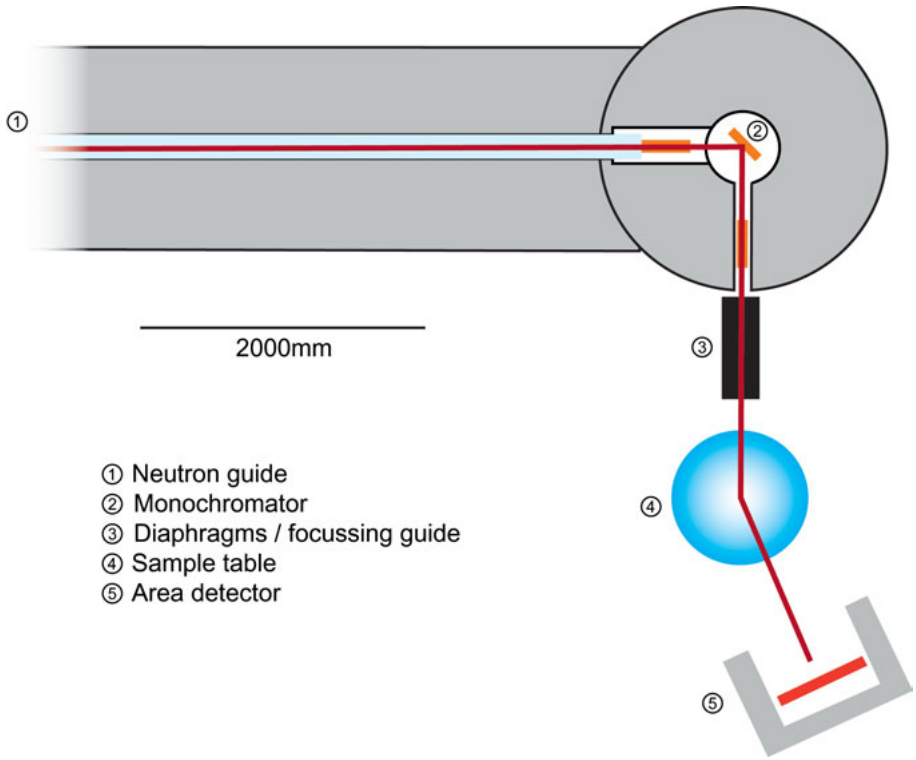
- Oxford Instruments Helijet
  temperature range 15 K - 100 K
  consumption ~ 2 l L-He / h
  sample size 1×1×1 mm^3 max

FRM II standard sample environment usable with RESI

- Closed-cycle cryostat CC, 2.5 K – 300 K
- Closed-cycle cryostat CCR, 3 K – 100 K
  using ^{3}He insert, 500 mK – 4 K
  using ^{3}He/^{4}He dilution, 50 mK – 1 K
- Vacuum furnace, 340 K – 2100 K
- Mirror furnace, RT – 1250 K

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

UNIA Universität Augsburg University



Technical Data

Primary beam

- Beam tube SR8b
- Neutron guide
  Length: 12 m, focussing vertical / horizontal
  Section: 70 × 40 mm → 60 × 30 mm
- Coatings: m = 3 top/bottom; m = 1 side

Monochromators

Vertically focussing lamella type, fixed take-off 90°

- Cu-422, 20' mosaic,1 Å : $2 \cdot 10^6$ n/cm²s
- Ge-511, 25' mosaic (deformed wafer stack)
  1,5 Å : $6 \cdot 10^6$ n/cm²s

Secondary neutron guide

Vertically focussing ellipitical guide-in-guide

- length:1 m
- focus 400 mm after guide exit
- coating: m = 5

Available goniometers

- Kappa-Goniometer
  Bruker-Nonius Mach3
  carrying capacity: max 100 g
- Eulerian cradle Huber 420
  higher carrying capacity, e.g. for closed-cycle cryostat
- Huber 2-circle goniometer with tilting head
  highest carrying capacity, e.g. for CCR with ^{3}He insert

Available detectors

- MAR345 image plate detector
  345 mm diameter, N-sensitive image plate
- Single counter ^{3}He with optional analyzer
  for pure elastic scattering

Dr. Bjørn Pedersen

Phone: +49.(0)89.289.14707
Email: bjoern.pedersen@frm2.tum.de

Phone Instrument: .14827

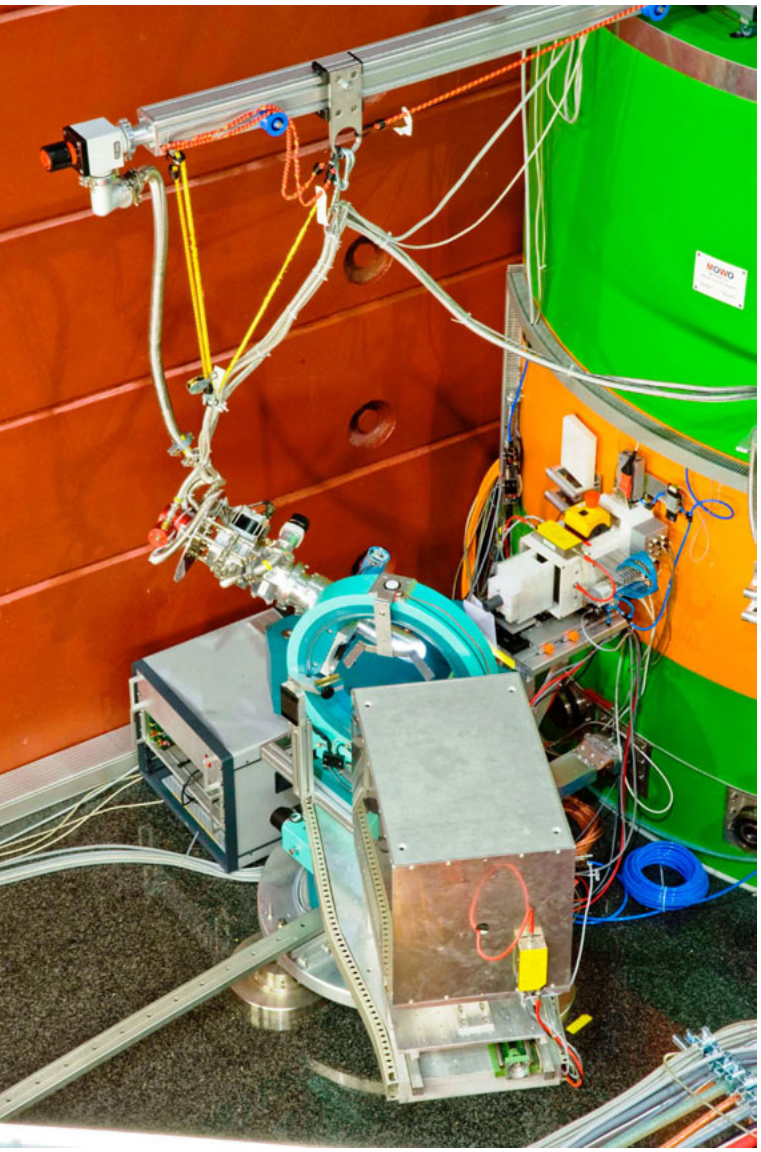
Dr. Wilhelm Klein

Phone: +49.(0)89.289.14626
Email: wilhelm.klein@frm2.tum.de

www.frm2.tum.de/resi

HEIDI

single crystal diffractometer on hot source



Description

The single crystal diffractometer HEiDi is designed for detailed studies on structural and magnetic properties of single crystals using unpolarized neutrons and Bragg's Law:

$2\, d_{hkl} \sin(\Theta) = \lambda$

Because of the large variety of short wavelengths and resolutions (see figure 1) HEiDi is suitable for studies on many crystalline compounds like:

- HT superconductors (e.g. cuprates, FeAs-pnictides)
- Multiferroics (e.g. manganites) and other complex ferro- and antiferromagnetic compounds (e.g. Co-olivines)
- Ionic conductors (e.g. nickelates)
- Ferrolelectrica (e.g. KDP family)
- Mixed crystals (e.g. AsSe compounds)
- Highly absorpbing compounds (e.g. with Gd, Sm, Eu)

Applications (in general)

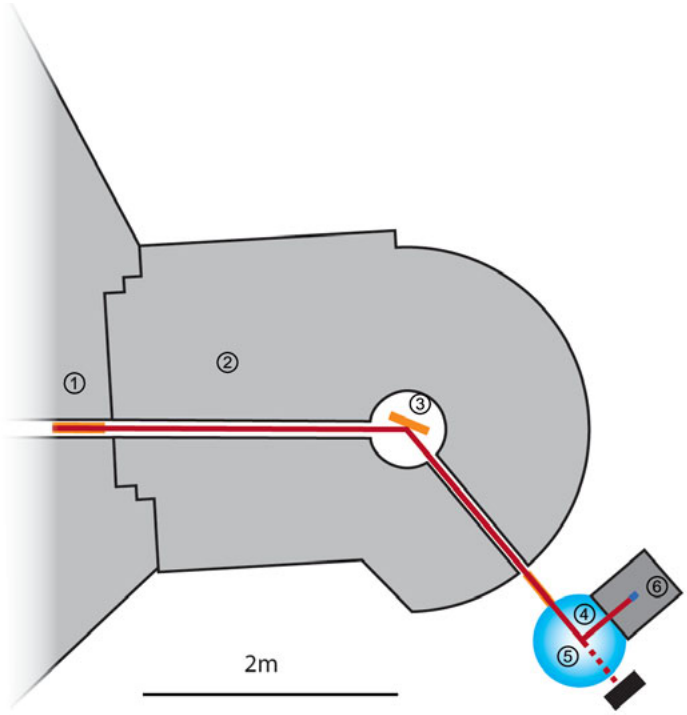
- Structure analysis
- Hydrogen bonds
- Static and dynamic disorder
- Harmonic and anharmonic mean square displacements
- Twinning
- Magnetic structure and order
- Spin densities
- Structural and magnetic phase transitions
- Incommensurate structures

Applications (in detail)

- Studies of atomic positions and bond distances in compounds with heavy and light elements or elements of similar electron shells
- Temperature dependent studies for determination of phase transitions
- Studies of order-disorder phase transitions, e.g. H bonds by determination of anisotropic mean square displacements using large Q range up to $\sin(\Theta)/\lambda > 1$
- Structure determination of compounds with hiqhly absorbing elements (Gd, Sm, Cd) with short wavelengths
- Studies on magetic phase transitions and T dependencies (ferri, ferro and antiferro magnets, multiferroics)
- Studies on HT superconductors (e.g. cuprates, FeAs pnictides)
- Sample characterization by profile analysis
- Determination of sample orientation, e.g. for preparation of experiments on triple axes instruments
- Presentation of fundamentals of crystallography and structure analysis for education

Sample Environment

- Closed cycle cryostat (2 K – RT)
- Mirror furnace (RT – 2000 K)
- Micro furnace (RT – 500 K)
- Uniaxial pressure cell (from PUMA)



Technical Data

Beam-tube

SR9 (hot source)
Flux at sample $9 \cdot 10^6$ $cm^{-1}s^{-1}$ ($\lambda \approx 1.1$ Å)
Gain by hot source (at sample) × 10 for $\lambda \approx 0.5$ Å

Wavelength

$2\Theta_M$	Ge(311)	Cu(220)	Cu(420)
20°	0.503	0.443	0.280
40°	1.168	0.870	0.552
50°	1.443	1.079	0.680

Q-range

$2\Theta_M$	Ge(311)	Cu(220)	Cu(420)
20°	1.46	1.95	3.09
40°	0.74	0.99	1.57
50°	0.60	0.80	1.27

Detectors

- Single detector optimized for small wavelengths (sensitivity >90% at 0.3 Å)
- Area detector (200 × 200 mm^2, wire grid) for multiple peak and centering enhancement
- Analyzer PG(002); optional for studies of purely elastic scattering and background supression

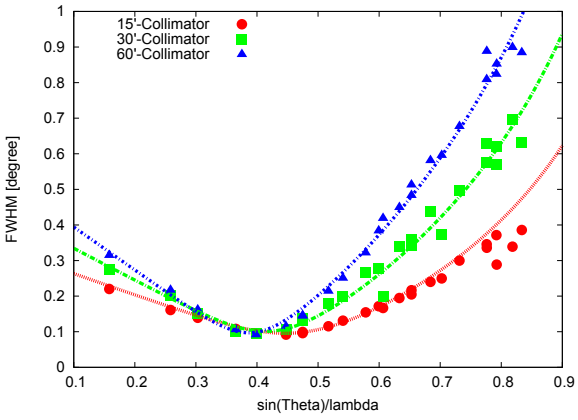


Figure 1: FWHM of reflections from a Si sample measured with a wavelength of 0.87 Å using the Cu (220) monochromator.

Dr. Martin Meven

Phone: +49.(0)89.289.14727
Email: martin.meven@frm2.tum.de

Phone Instrument: .14828

www.frm2.tum.de/heidi

POLI

polarized hot neutron diffractometer

Description

The diffractometer POLI is dedicated to the investigation of single cristalline samples with complex magnetic structures using neutron spin polarization.
Neutron beam polarization P can be treated as a classical vector. Zero-field spherical neutron polarimetry (SNP) allows to measure all components of the scattered polarization vector. Determining the relationship between the directions of incident and scattered polarizations gives access to the 16 independent correlation functions involved in the most general nuclear and magnetic scattering process. Generally this leads to the determination of the direction of the magnetic interaction vectors of magnetic structures. For those structures, in which nuclear and magnetic reflections coincide in reciprocal space, SNP leads to the determination of the amplitude of the magnetic interaction vectors, and hence to the magnetisation distribution.
Currently the instrument uses the focused monochromatic beam from the monochromator of the single crystal diffractometer HEiDi at the beam channel 9b. The construction of the separate dedicated for POLI monochromator at the beam channel 9a is on the way and will be finalized in 2013.
The separation between monochromator and polarizer allows the use of the polarized neutrons with different wavelengths and high resolution. This feature of POLI is rather unique especially for hot neutrons.
The incoming beam is polarized along the beam axis by mean of ^{3}He spin filter cell (SFC) placed in the polarizer magnetostatic cavity. The polarization of the incoming beam is determined by the transmission measurement of the SFC using two beam monitors. SNP is implemented on POLI using the zero-field polarimeter Cryopad of the third generation. Nutator and incoming precession coil of the Cryopad precisely turn the polarization vector of the incoming beam along any required direction. The outgoing precession coil and second nutator turn the required component of the polarization along the quantization axis of the analyser (SFC in Decpol). X, Y, Z components of the scattered polarization are measured for each orientation of the incoming polarization and hence a polarization matrix of 9 elements for an individual Bragg reflection is determined. The count rates for the two spin states are corrected for background.
To achieve the best available accuracy optimum strategy is applied for each reflection. The in-situ measurements of the incoming polarization permit easy correction of the measured data regarding the time dependence of the SFCs. Dedicated software for SNP instrument control and data analysis developed at ILL is used. The collected data sets can easily be exported, processed and automatically plotted. Further development of the data refinement software is on the way.

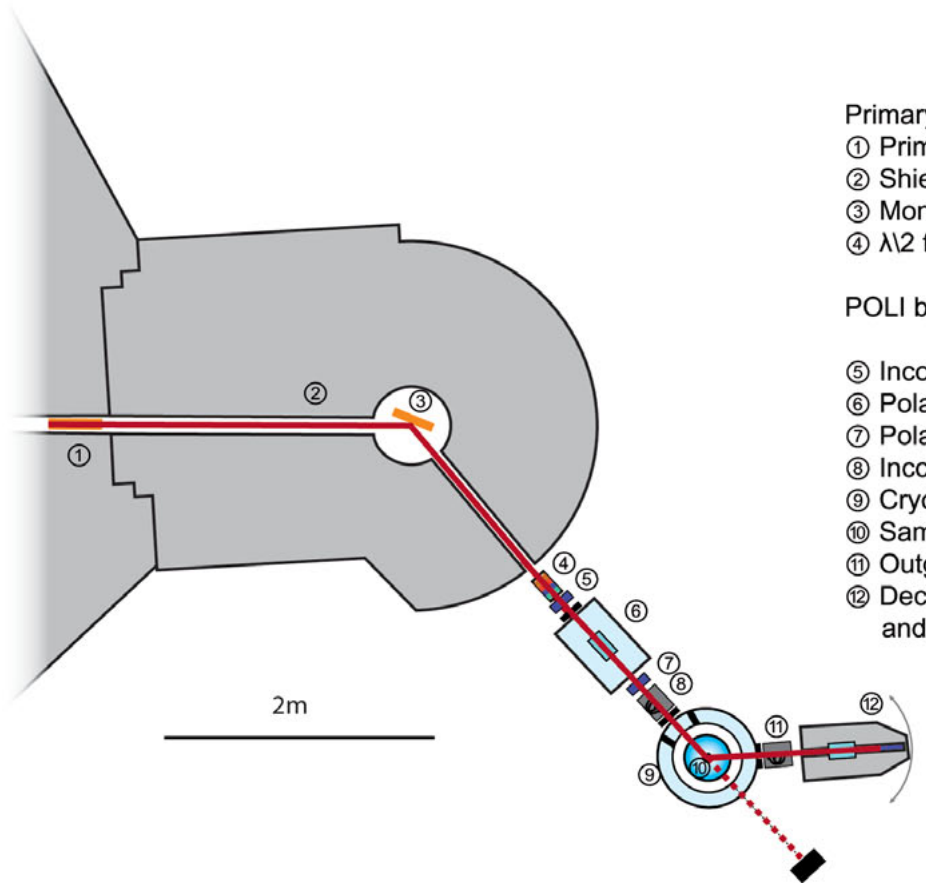
Typical Applications

- Complex commensurate and incommensurate magnetic structures studied in ground state (zero-field), this could be very useful especially for superconductors
- Temperature dependence of the magnetic structure
- Studies of magnetic or magneto-electric domains using zero-field SNP on the samples cooled in zero-field as well as in high external magnetic field (up to 7.5 T). The combination of magnetic and electric fields applied on the sample could be important for the studies on multiferroic materials.
- Determination of anti-ferromagnetic form factors

Sample Environment

- Standard FRM II closed-cycle cryostat (4 K – 300 K)
- Low temperature inserts or cryofurnace option on request

RWTH AIXtal
Bundesministerium für Bildung und Forschung



Primary beam from HEiDI
① Primary Beam Collimator
② Shielding
③ Monochromator
④ λ\2 filters

POLI backend

⑤ Incoming beam monitor
⑥ Polarizer (with ^{3}He spin filter)
⑦ Polarized beam monitor
⑧ Incoming nutator
⑨ Cryopad
⑩ Sample table
⑪ Outgoing nutator
⑫ Decpol (^{3}He polarization analyzer and detector)

Technical Data

Primary beam (HEiDi)

Beam tube SR9 on hot source

Focussing monochromators

crystal	wavelength λ [Å] at $2\theta_M$			flux at $2\theta_M = 40°$
	20°	40°	50°	
Ge (311)	0.593	1.116	1.443	$9 \cdot 10^6$ n cm^{-2}s^{-1}
Cu (220)	0.443	0.870	1.079	$4.3 \cdot 10^6$ n cm^{-2}s^{-1}
Cu (420)	0.280	0.552	0.680	$2.0 \cdot 10^6$ n cm^{-2}s^{-1}

Diffractometer angles

with Cryopad	without Cryopad
$-10° < 2\theta < 120°$	$-130° < 2\theta < 130°$
$-180° < \omega < 180°$	$-180° < \omega < 180°$
$-4° < \chi_1 < 4°$	$-5° < \chi_1 < 5°$
$-4° < \chi_2 < 4°$	$-5° < \chi_2 < 5°$

Neutron polarization

^{3}He spin filter cell	$65\ \% < P_{3He}(0) < 75\ \%$	
	$100\ h < T_1 < 200\ h$	
Neutron beam polarization with cell $P_{3He}(0) = 70\ \%$ and T1 = 100 h	initial	after 24 h
	> 0.92	> 0.80
Cell replacement,	daily	
Time for cell replacement	< 2 min.	

Cryopad (zero-field polarimeter)

- LHe refill (manual): 1/week
- LN_2 refill (automatic): daily
- Sample space for closed cycle cryostat or orange type cryostat
- Max. sample size: 25 mm

Dr. Vladimir Hutanu

Phone: +49.(0)89.289.12153
Email: vladimir.hutanu@frm2.tum.de

Phone Instrument: .14828

www.frm2.tum.de/poli-heidi

SPODI

high resolution powder diffractometer

Description

The high resolution powder diffractometer SPODI is designed for the structure solution and Rietveld refinement of structural parameters on crystalline powders. The instrument is characterized by a very high monochromator take-off angle of 155° (standard configuration). Optionally, a take-off angle of 135° is available.

The detector array consists of 80 ^{3}He position sensitive detector tubes (300 mm active height) with fixed Soller collimators of 10‘ horizontal divergence. The multidetector of SPODI spans an angular range of 2θ = 160°. As each detector covers 2° corresponding to 160° / 80 detectors. The data collection is performed via stepwise positioning of the detector array to obtain a diffraction pattern of the desired step width (typically 2° / 40 steps resulting in Δ(2θ) = 0.05°).

The two-dimensional raw data are evaluated to provide diffraction patterns corresponding to different detector heights ranging from 10 mm to 300 mm and variable detector height, accounting for vertical beam divergence effects (see figure 1). Thus, asymmetric broadenings at quite low and high scattering angles are overcome, while the full detector height in the medium 2θ regime can be used.

Various sample environmental devices enable the characterization of materials under special conditions: A rotatable tensile rig allows in-situ studies under tensile stress, compression stress or torsion while the load axis can be oriented with respect to the scattering plane. A potentiostat for charging/discharging of Lithium ion batteries is available as well as a device to apply high electric fields on ferroelectrics. Additional apparatuses for the in-situ charging of catalysers with sorbents or the study of hydrogen storage materials under high deuterium pressures and elevated temperatures will be available in future.

Typical Applications

- Determination of complex crystal and magnetic structures
- Structural evolutions and phase transformations under various environmental conditions.
- Static and thermal disorder phenomena
- Study of ionic conductors
- Study of H-Storage materials

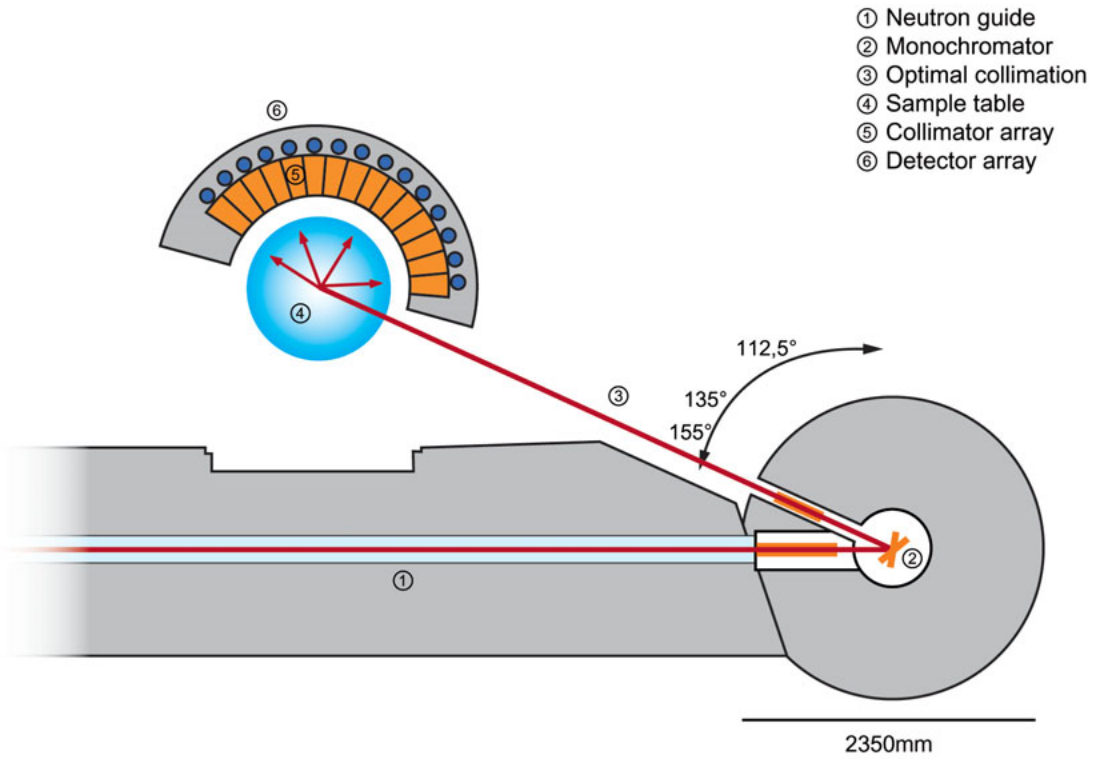
Sample Environment

Standard sample environment of FRM II

- Closed cycle cryostat 3 – 550 K
  (with ^{3}He insert: T_{min} = 500 mK)
- Vacuum high temperature furnace
  T_{max} = 1900 °C
- Cryomagnet
  B_{max} at SPODI: 5 T, T_{min} = 4 K

Special sample environment

- Rotatable tensile rig
  F_{max} = 50 kN, M_{max} = 50 Nm
- Device for electric fields
  V_{max} = 35 kV
- Potentiostat for electrochemical treatment of materials VMP3
- Mirror furnace
  T_{max} = 1200 °C
- Paris-Edinburgh pressure cell
  P_{max} = 10 GPa



Technical Data

Monochromator

Ge(551) wafer stack crystals
standard configuration: take-off angle 155°

- Ge(551): 1.548 Å
- Ge(331): 2.436 Å
- Ge(711): 1.111 Å

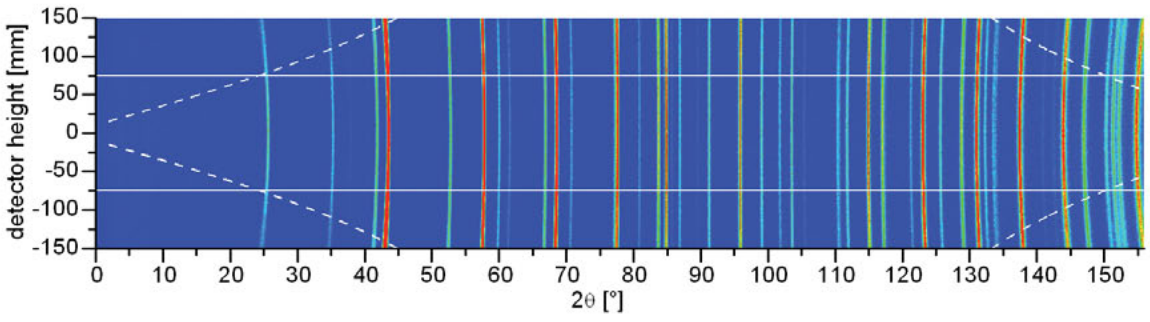
Collimation

- α1 ≈ 20’ (neutron guide)
- α2 = 5’,10’, 20’, 25’ nat. (for 155°)
  α2 = 10’, 20’, 40’ nat. (for 135°)
- α3 = 10’

Detector array

80 position-sensitive ^{3}He tubes,
angular range 2θ = 160°

Figure 1: Two-dimensional data set of a corundum reference sample. The straight white lines bound a detector height of 150 mm and the detector height 0 denotes the central line of the detector. The dotted white lines encompass the data used in the “300 mm - variable height” data set.



Dr. Markus Hölzel

Phone: +49.(0)89.289.14314
Email: markus.hoelzel@frm2.tum.de

Phone Instrument: .14826

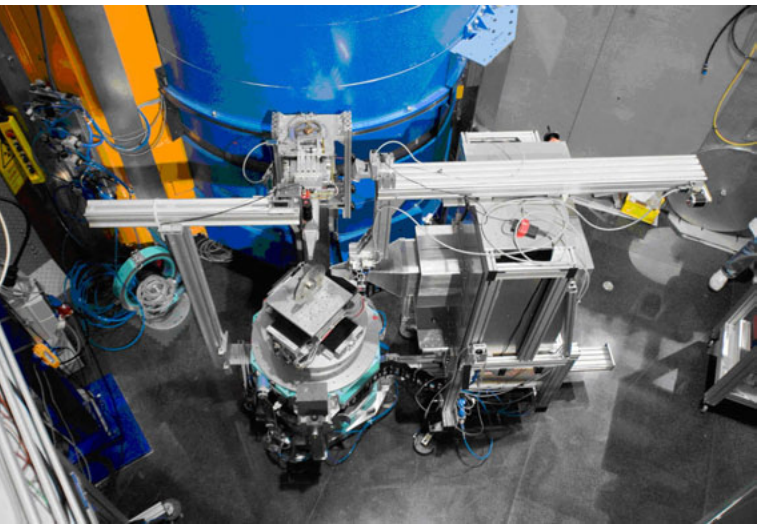
Dr. Anatoliy Senyshyn

Phone: +49.(0)89.289.14316
Email: anatoliy.senyshyn@frm2.tum.de

www.frm2.tum.de/spodi

STRESS-SPEC

materials science diffractometer



Description

In response to the development of new materials and the application of materials and components in new technologies the direct measurement, calculation and evaluation of textures and residual stresses has gained worldwide significance in recent years.
The materials science diffractometer STRESS-SPEC is located at the thermal beam port SR3 of the FRM II and can easily be configured either for texture or stress analysis.
The setup utilizes three different monochromators: Ge (511), bent silicon Si (400) and pyrolitic graphite PG(002). This selection of monochromators and the possibility to vary automatically the take-off angles from $2\theta_M$ = 35° to 110° allows to find a good compromise between resolution and intensity for each measuring problem.
The gauge volume defining optical system of primary and secondary slits is designed with regard to reproducibility of geometrical alignment and sturdiness. Both slit systems are linked to the sample table and the detector in such a way that the center of the beam remains the same under all conditions. Therefore new alignment will not be necessary even in case the wavelength or the slit to sample position has been changed.
Samples can be aligned using theodolites and a camera system. In addition the possibility to scan surfaces of components offline using a CMM laser scanner is available at STRESS-SPEC.

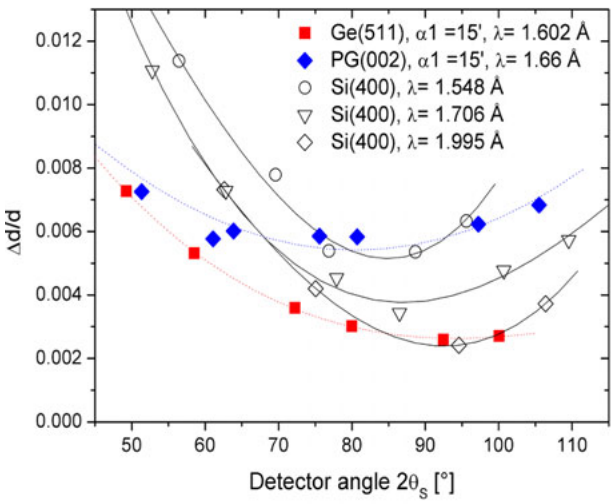


Figure 1: resolution function for different monochromator options

Typical Applications

Residual stress analysis

- Industrial components
- Welds
- Superalloys
- Strain mapping

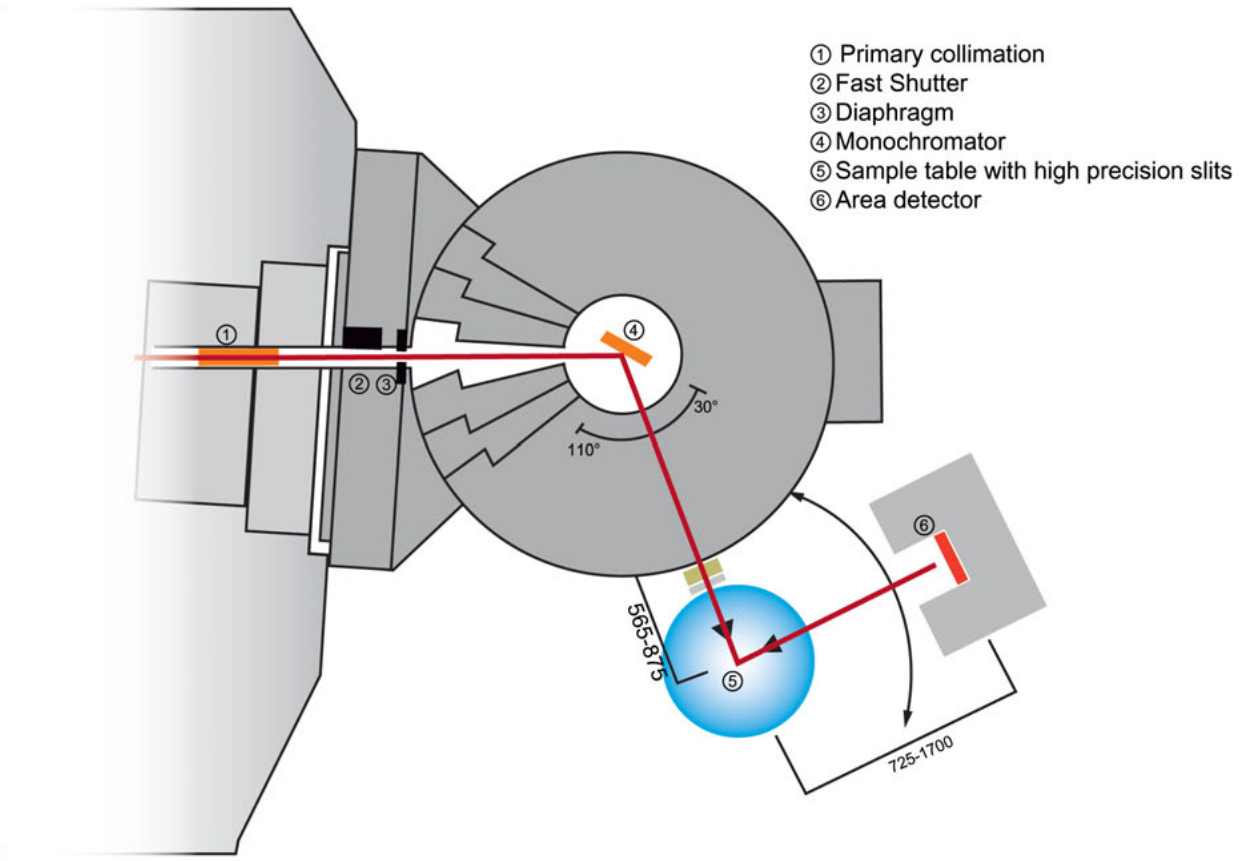
Texture determination

- Global textures
- Local textures
- Strain pole figures
- FHWM pole figures

Sample Environment

- XYZ-table
  capacity 300 kg, Travel xy = ±120 mm,
  z = 300 mm, accuracy ~ 10 µm
- Load frame
  +/- 50 kN and cyclic loading
- Bending machine
- Full circle Eulerian cradle (max. load 5 kg)
- ¼ circle Eulerian cradle for heavy samples
- Standard sample environment FRM II
  (e.g. furnace)

A positioning system consisting of a Stäubli-6-axis robotic arm for texture and strain measurements (payload up to 30 kg) can be mounted instead of the standard sample table. It offers more flexibility than an Eulerian cradle and in future it will be also used as automatic sample changer for texture measurements.



Technical Data

Neutron beam

SR3 thermal neutrons
Collimators ('in-pile') 15', 25', open

Monochromators

Ge (511), Si (400), PG (002)
$2\theta_M$ 35° – 110° continuous
wavelength 1 Å – 2.4 Å ; (2.5 $Å^{-1}$ < Q < 10.5 $Å^{-1}$)

Possible slit size - Residual Stress

Primary slit: 1 x 1 mm^2 up to 5 x 20 mm^2 (W x H)
Secondary slit: continuously variable up to 15 mm
Radial collimators (FWHM = 2 mm, 5 mm)

Possible slit size – Textures

Primary slit: max. 30 x 40 mm^2 (W x H)
Secondary slit: continuously variable up to 15 mm or open

Detector

^{3}He-PSD, 30 x 30 cm^2; 256 × 256 pixel

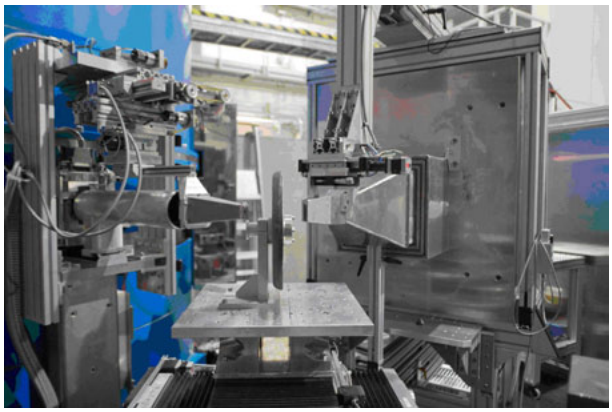


Figure 2: Slit-system for residual stress analysis

Dr. Michael Hofmann

Phone: +49.(0)89.289.14744
Email: michael.hofmann@frm2.tum.de

Phone Instrument: .14814

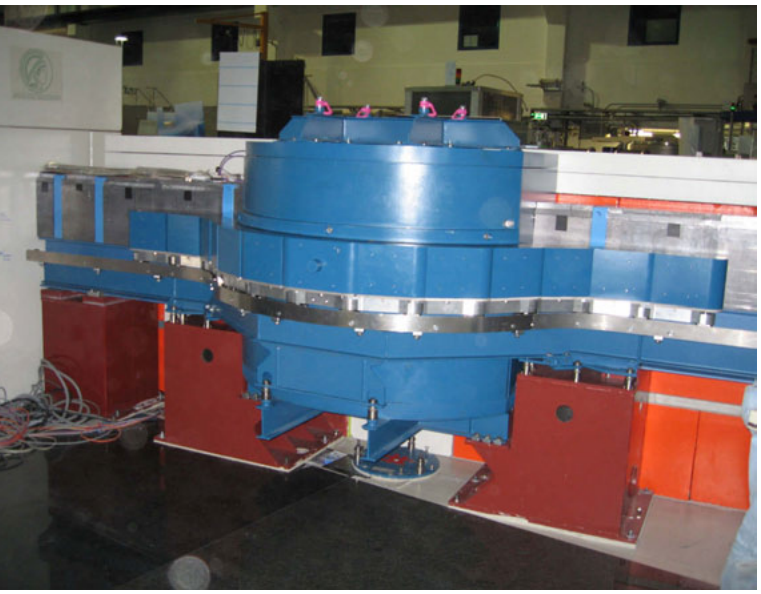
Dr. Weimin Gan

Phone: +49.(0)89.289.10766
Email: weimin.gan@gkss.de

www.frm2.tum.de/stressspec

BIODIFF

diffractometer for large unit cells



Description

The monochromatic single crystal diffractometer BIODIFF is a joint project of the FRM II and the Forschungszentrum Jülich (FZJ).

BIODIFF is designed to handle crystals with large unit cells and is dedicated to the structure determination of biological macromolecules. In biological macromolecules, like proteins and nucleic acids, hydrogen atoms play an important role. Hydrogen atoms take part in the substrate binding process and are essential for proton transfer reactions during the catalysis in many enzymes. Therefore the knowledge about the protonation states of amino acid residues in the active centre of proteins is often crucial for the understanding of their reaction mechanisms. However, hydrogen atoms, especially rather flexible ones, are barely detectable in X-ray structure determinations of proteins. On the other hand, hydrogen atoms are clearly visible in neutron crystallography experiments even at moderate resolutions ($d_{min} < 2.0$ Å).

BIODIFF is the first instrument along the cold neutron guide NL-1 and is positioned in a distance of about 32.5 m to the cold source. Using a pyrolytic graphite monochromator PG(002) the diffractometer will be able to operate in the wavelength range of 2.4 Å to about 5.6 Å. Higher order wavelength contaminations will be removed by a neutron velocity selector. The main detector of the diffractometer consists of a neutron imaging plate system in a cylindrical geometry to cover a large solid angle. A fast LiF/ZnS scintillator CCD camera is foreseen for additional detection abilities. The main advantage of this instrument is the possibility to adapt the wavelength to the size of the unit cell of the sample crystal while operating with a clean monochromatic beam that keeps the background level low.

Typical Applications

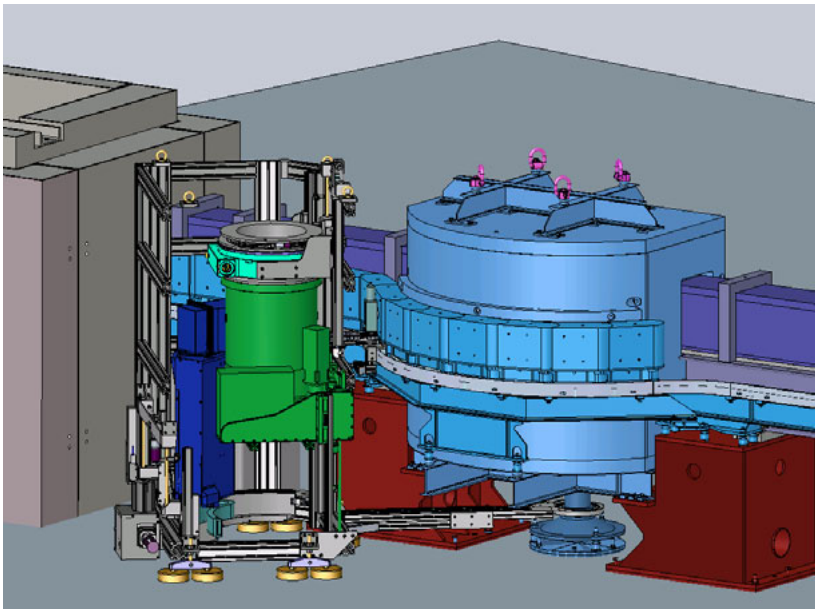
The main field of application is the neutron structure analysis of proteins, especially the determination of hydrogen atom positions. Typical questions in this field of interest are:

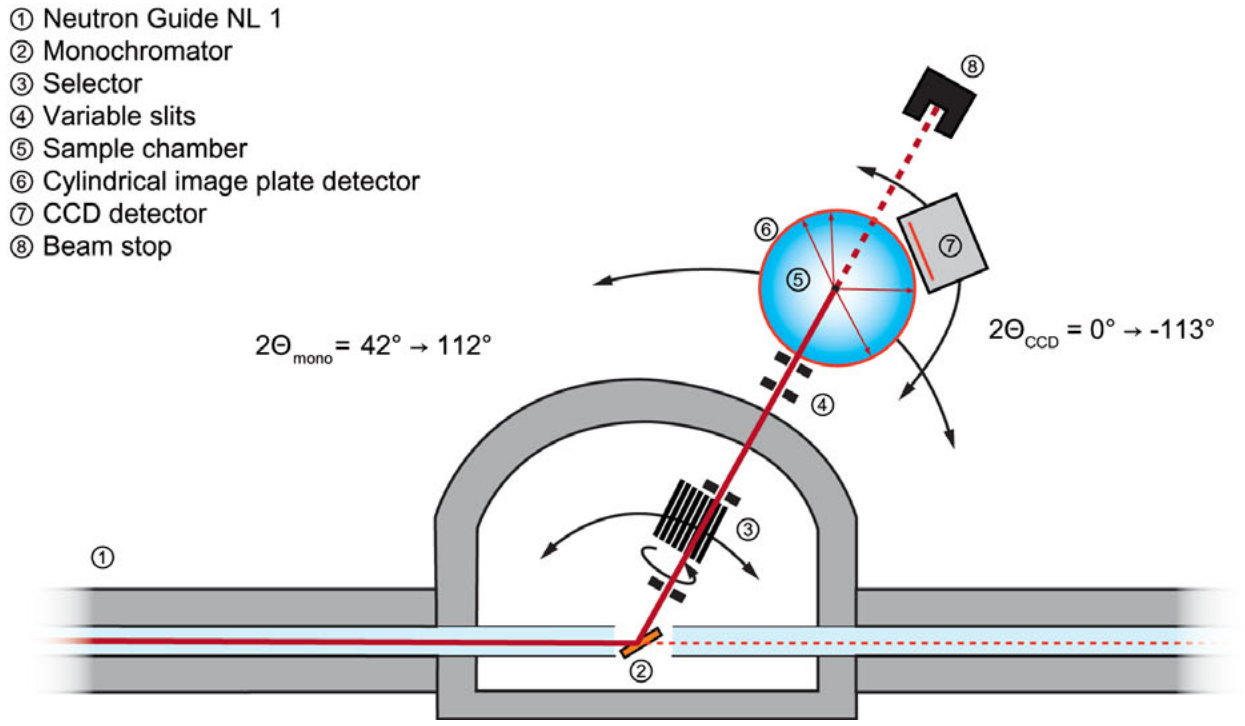
- Enzymatic mechanism (protonation states of amino acids)
- Ligand binding mediated by hydrogen bonds
- Investigation of the hydration shell of proteins
- H/D-exchange pattern as a monitor of structural stability/flexibility

Sample Environment

Besides FRM II standard sample environment BIODIFF provides:

- Oxford Cryosystems Cryostream 700 plus 90 – 500 K





Technical Data

Primary beam

- Neutron guide NL-1; supermirror m = 2
- Monochromator:
  PG(002)
  mosaicity: 0.4 – 0.5°
- Higher order filter:
  Astrium type velocity selector
  transmission 87% for 2.4 Å
- Wavelength range:
  2.4 - 5.6 Å with selector
  2.4 - 6.1 Å without selector
- Collimation by adjustable slits down to
  Ø = 1 mm

Beam properties at the sample position*

- Wavelength resolution at sample position:
  $\Delta\lambda/\lambda$ = 2.9 % at 2.4 Å
- Beam divergence (no slits)
  0.8° FWHM horizontal
  0.7° FWHM vertical

*1 expected values by Monte-Carlo simulations

Main detector

Neutron image plate (cylindrical)

- $BaFBr:Eu^{2+}$ mixed with Gd_2O_3
- Dimensions:

radius	200 mm
angular range	±152° horizontal
	±48° vertical

- Pixel size 125, 250, 500 µm²
- Readout time (with erasing):
  5 min (for 250 µm pixel size)

Auxiliary detector

CCD camera with scintillator

- ZnS mixed with ^6LiF
- Dimensions:

Active scintillator area (flat)	200 x 200 mm²
Distance to sample	100 mm

- 2Θ-angle around sample position 0° - 113°
- CCD chip with 2048 x 2048 pixels
- Pixel size: 13.5 µm²
- Overall spatial resolution ≈ 300 µm² (limited by scintillator thickness)
- Minimum readout time
  ≈ 1 sec (full resolution); < 1 sec (binning mode)

Dr. Tobias Schrader

Phone: +49.(0)89.289.10743
Email: t.schrader@fz-juelich.de

Phone Instrument: .14565

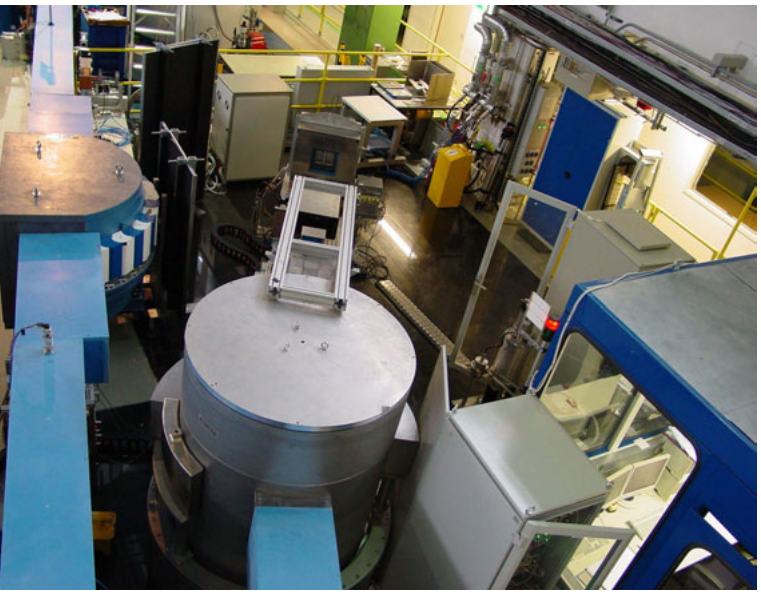
Dr. Andreas Ostermann

Phone: +49.(0)89.289.14702
Email: Andreas.Ostermann@frm2.tum.de

www.frm2.tum.de/biodiff

MIRA

multipurpose instrument



Description

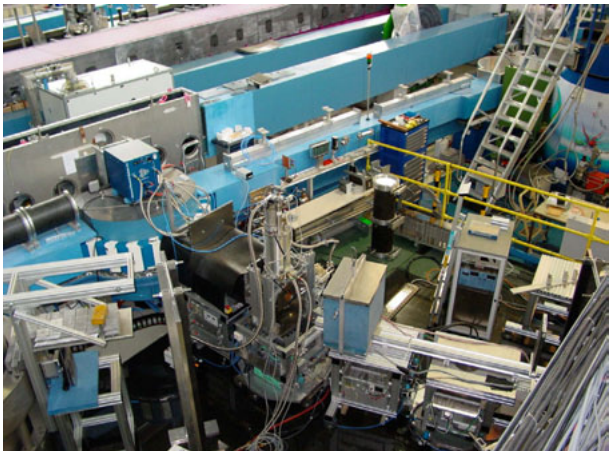
MIRA is a multipurpose instrument at the FRM II. With its two beam ports, namely MIRA-1 and MIRA-2, it provides neutrons over a wide range of wavelengths 3.5 Å < λ < 20 Å. The instrument can easily be moved from one port to the other without changing the sample environment. The large variety of different options offered can also be combined in most cases. This allows for a fast realisation of experiments in a very flexible way using a number of available options:

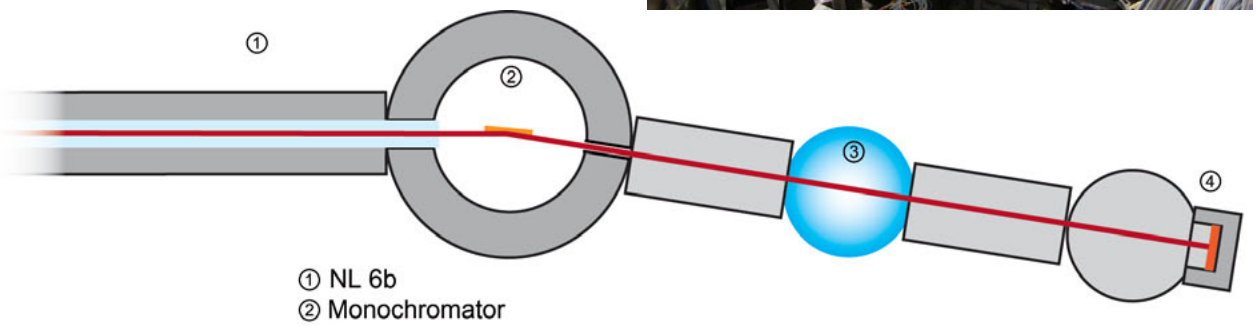
- Small angle neutron scattering (SANS)
- MIEZE (a type of neutron spin echo method working in magnetic fields)
- Reflectometry
- 3D-Polarimetry
- Cold diffraction (in construction)
- Cold three axes for extreme environments (in design phase)

As most experiments are done in modest magnetic fields MIRA has a water-cooled electromagnet, which can be rotated independently from the sample and delivers fields from -0.3 T to 0.3 T. The 7.5 T cryo-magnet of the FRM II standard sample environment can also be used.

Typical Applications

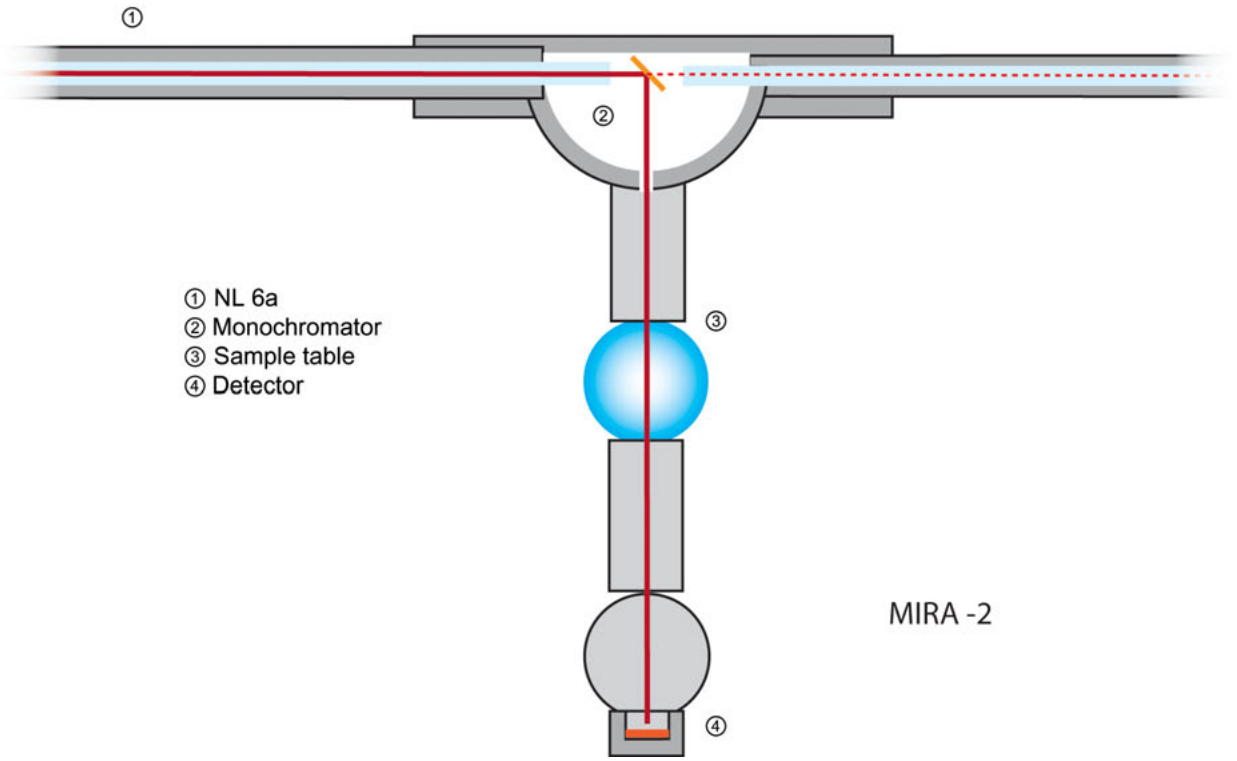
- Determination of magnetic structures, especially large scale structures, i.e. helical spin density waves or magnetic lattices
- Quasi-elastic measurements in magnetic fields with high resolution
- Determination of structures and dynamics in extreme environments, like pressure (being implemented)
- Determination of layer thickness of films, for instance in polymer physics
- Reflectometry from magnetic multilayers
- Polarization analysis





① NL 6b
② Monochromator
③ Sample table
④ Detector

MIRA -1



Technical Data

MIRA-1

Primary beam

Neutron guide: NL6 S
Dimensions: 10 x 120 mm² (width x height)
Curvature: 84 m
Coating: sides m = 1.2, top/bottom m = 2

Monochromator

Multilayer $\Delta\lambda/\lambda \approx 3\%$ (5% polarized)
8 Å < λ < 20 Å

max. differential flux at sample

$5 \cdot 10^5$ neutrons/ Å s cm² at 10 Å
$2 \cdot 10^5$ neutrons/ Å s cm² polarized

Analyzer

2 Bender
^{3}He-Spin filter

Detector

20 x 20 cm² 2-D PSD with 1 x 2 mm² resolution
1 inch ^{3}He finger detector
^{6}Li doped scintillator + PMT, time resolution < 1 ps
20 x 20 cm² 2-D PSD, time resolution < 1 ps

MIRA-2

Primary beam

Neutron guide: NL6 N
Dimensions: 60 x 120 mm² (width x height)
Coating: sides m = 1.2, top/bottom m = 2

Monochromator

Horizontal focussing HOPG $\Delta\lambda/\lambda \approx 2\%$
3.5 Å < λ < 6 Å

max. differential flux at sample

$5 \cdot 10^7$ neutrons/ Å s cm² at 4.7 Å
$1 \cdot 10^6$ neutrons/ Å s cm² polarized (in preparation)

Analyzer

S-Bender, transmission polarizer (in construction),
^{3}He-Spin filter

Detector

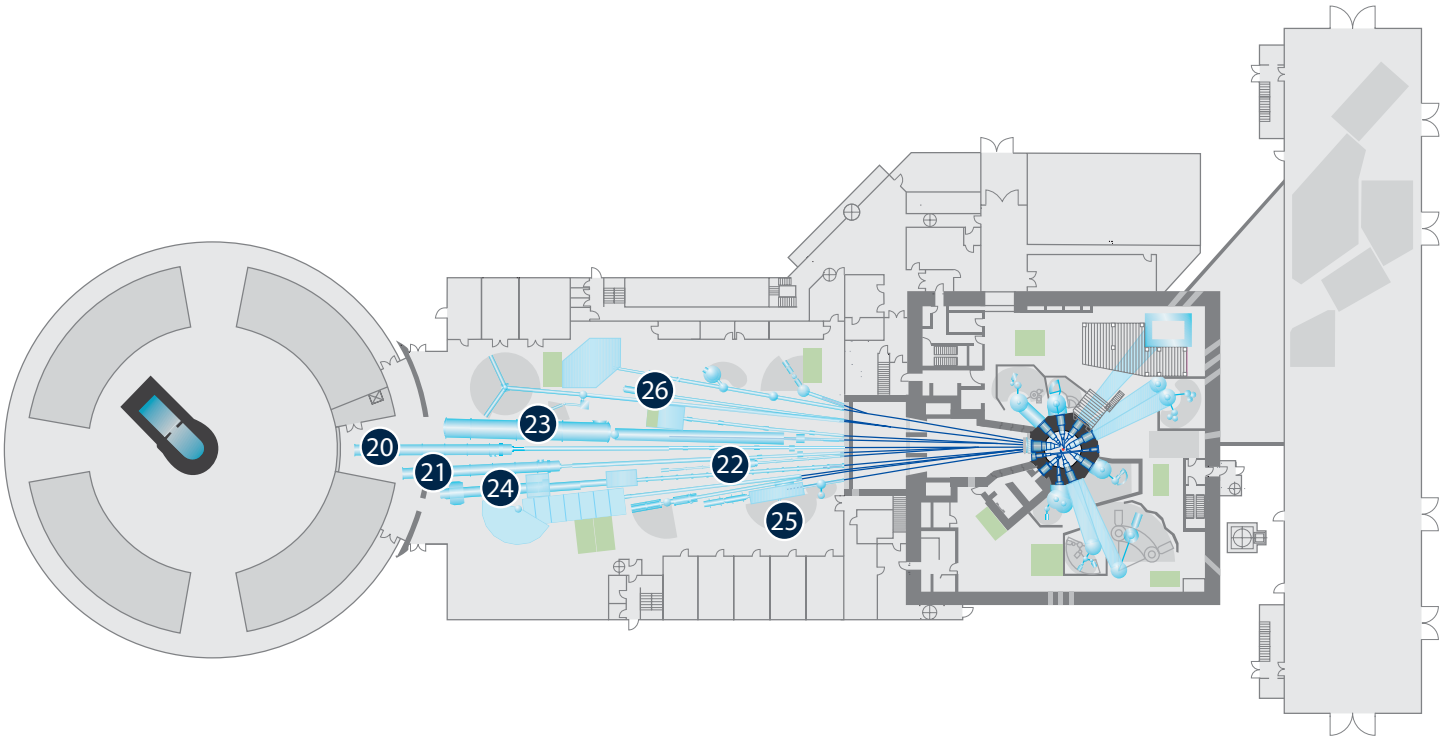
20 x 20 cm² 2-D PSD with 1 x 2 mm² resolution
1 inch ^{3}He finger detector
^{6}Li doped scintillator + PMT, time resolution < 1 ps
20 x 20 cm² 2-D PSD, time resolution < 1 ps

Dr. Robert Georgii

Phone: +49.(0)89.289.14986
Email: robert.georgii@frm2.tum.de

Phone Instrument: .14877

www.frm2.tum.de/mira



20 **KWS-1**
small angle scattering
diffractometer
p. 32 / 33

21 **KWS-2**
small angle scattering
diffractometer
p. 34 / 35

22 **KWS-3**
very small angle scattering
diffractometer
p. 36 / 37

23 **SANS-1**
small angle scattering
diffractometer
p. 38 / 39

24 **REFSANS**
reflectometer and evanescent
wave small angle diffractometer
p. 40 / 41

25 **N-REX+**
reflectometer
with X-ray option
p. 42 / 43

26 **MARIA**
reflectometer

p. 44 / 45

SANS & Reflectometry

KWS-1

small angle scattering diffractometer

Description

The KWS-1 is dedicated to high resolution measurements due to its 10 % wavelength selector. This property is interesting for highly ordered or highly monodisperse samples. With the foreseen chopper the wavelength uncertainty can be reduced further to ca. 1 %. The scientific background of KWS-1 is placed in magnetic thin films. Magnetic samples will be studied with the full polarization analysis including incident beam polarization and polarization analysis of the scattered neutrons. In front of the collimation, a 3-cavity polarizer with V-shaped mirrors is placed. The full bandwidth of 4.5 to 20 Å will be covered with min. 90 % (95 % typical) polarization. A radio frequency spin flipper allows for changing the polarization. The polarization analysis will be realized with ^{3}He-cells which will be optimized for the used wavelength and scattering angle. Horizontal and vertical magnets will be provided to render the magnetic field at the sample position. Thin films can be well studied in the grazing incidence geometry – the method is called grazing incidence small angle neutron scattering (GISANS). A newly installed hexapod will allow for positioning the sample with 0.01 mm and 0.01° precision.
Classical soft-matter systems will be investigated on KWS-1 if the resolution is needed. Biological samples can be handled due to the detector distance of ca. 1 m, which will allow for maximal scattering angles of Q = 0.5 Å^{-1}. Extremely low Q of 10^{-4} Å^{-1} will be provided in the high resolution mode. A high resolution detector at ca. 17 m distance will allow for detecting smallest scattering angles. In parallel, MgF_2 neutron lenses provide the focusing needed for this experiment.

The other application of neutron lenses is the high flux mode with large sample areas, while the resolution stays in the classical SANS range. These enhanced intensities allow for real time measurements in the 1/10 second region (typical 1 s).
The chopper in parallel allows for studying faster dynamics in the ms range. The so called TISANE mode interlocks the chopper frequency with the excitation field frequency and with the detection binning. The precise consideration of the flight times allows for higher precision compared to classical stroboscopic illuminations.

Typical Applications

- Grain boundaries
- Alloys
- Magnetic structures
- Flow lines
- Soft matter and biology (as for KWS-2)
- Complex fluids near surfaces
- Polymer films
- Magnetic films
- Nanostructured films

One example of a complex fluid near planar surfaces is discussed in context of figure 1. For enhanced oil recovery often aqueous surfactant systems are used, which, in contact with oil, form microemulsions. The current study focuses on bicontinuous microemulsions adjacent to a planar hydrophilic wall. The surface near structure is lamellar and decays to the bulk structure. Interestingly, this decay is realized by perforated lamellae. Currently, flow experiments are performed.

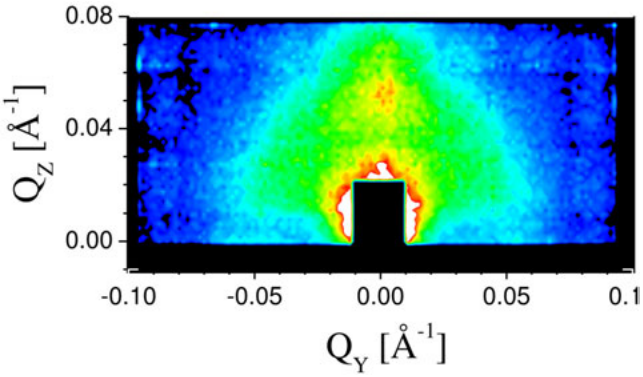
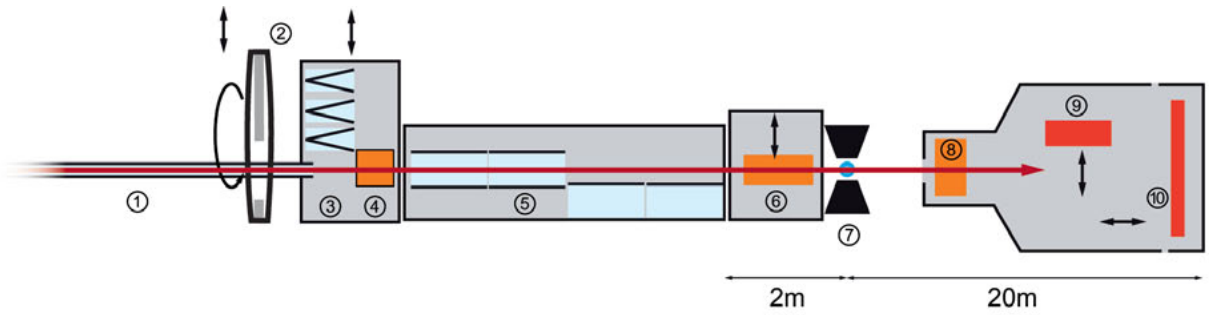


Figure 1: GISANS pattern of a microemulsion adjacent to a planar wall. The Bragg peak indicates the lamellar order induced by the wall. A weak Debye-Scherrer ring arises from the bicontinuous bulk structure.



① Neutron guide NL3
② High-speed chopper
$\Delta\lambda/\lambda$=1%
③ Changeable polarizers
④ Spin flipper
⑤ Neutron guide sections 18 x 1m
⑥ MgF_2 focusing lenses
⑦ Sample position with magnet
⑧ ^{3}He spin filter
with reversable polarization (in vacuum)
⑨ High resolution position-sensitive detector
⑩ Anger-type scintillation detector

Sample Environment

- Rheometer shear sandwich
- Rheowis-fluid rheometer (max. shear rate 10000 s^{-1})
- Anton-Paar fluid rheometer
- Stopped flow cell
- Sample holders: 9 horizontal x 3 vertical (temperature controlled) for standard Hellma cells 404.000-QX, and 110-QX
- Oil & water thermostats (typical 10 °C – 100 °C) electric thermostat (RT – 200°C)
- 6-positions thermostated (Peltier) sample holder (-40°C – 150°C)
- Magnet (horizontal, vertical)
- Cryostat with sapphire windows
- High temperature furnace
- Pressure cells (500 bar, 2000 bar, 5000 bar)

Technical Data

Overall performance

- Q = 0.0007 – 0.5 $Å^{-1}$
- Maximal flux: 1.5 · 10^8 n/cm^2/s
- Typical flux: 8 · 10^6 n/cm^2/s (collimation 8 m, aperture 30 x 30 mm^2, λ = 7 Å)

Velocity selector

Dornier, FWHM 10 %, λ = 4.5 Å – 12 Å, 20 Å

Chopper

for TOF-wavelength analysis, FWHM 1 %

Polarizer

Cavity with V-shaped supermirror, all wavelengths
Polarization better 90 %, typical 95 %

Spin-flipper

Radio-Frequency

Active apertures

2 m, 4 m, 8 m, 14 m, 20 m

Aperture sizes

rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Sample aperture

rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Neutron lenses

MgF_2, diameter 50 mm, curvature 20 mm
packs with 4, 6, 16 lenses

Sample stage

Hexapod, resolution better than 0.01°, 0.01 mm

Detector 1

Detection range: continuous 1 m – 20 m
^{6}Li-Scintillator 1 mm thickness + Photomultiplier
Efficiency better than 95 %
Spatial resolution 5.3 x 5.3 mm^2, 128 x 128 channels
Max. countrate 0.6 MHz (τ_{dead} = 0.64 µs)

Detector 2

Spatial resolution 0.45 x 0.45 mm^2
Active area: Ø = 8.7 cm
^{6}Li-Scintillator 1 mm thickness
Fixed position: 17 m after sample position

Dr. Henrich Frielinghaus

Phone: +49.(0)89.289.10706
Email: h.frielinghaus@fz-juelich.de

Dr. Marie-Sousai Appavou

Phone: +49.(0)89.289.10717
Email: m.s.appavou@fz-juelich.de

Dr. Zhenyu Di

Phone: +49.(0)89.289.10705
Email: z.di@fz-juelich.de

Phone Instrument: .14324

www.jcns.info/jcns_kws1

KWS-2

small angle scattering diffractometer

Description

The KWS-2 represents a classical pinhole SANS instrument with a typical Q-range from about 10^{-3} to 0.3 $Å^{-1}$ (fig. 1). It is dedicated to high intensity / wide-Q investigation of mesoscopic structures and structural changes due to rapid kinetic processes in soft condensed matter, chemistry and biology. The combination of high neutron flux supplied by the cold neutron source (CNS) of FRM II, newly designed neutron guide system [1], 20% wavelength selector, and new "fast" detection electronics supports the high-intensity operation mode. The neutron flux (fig. 2) is comparable with the world leading SANS instruments. The electronics of the Anger-type detection system (1mm thick ^{6}Li glass scintillator with an active area of 60x60 cm^2 and 95% detection probability for 7 Å) with a dead-time of 0.64 µs allows a counting rate of $1.5x10^5$ n/s with 10% dead-time assumed (with a maximum counting rate of about $6x10^5$/s). This opens opportunities to study rapid kinetic processes within the ms range (see fig. 3).

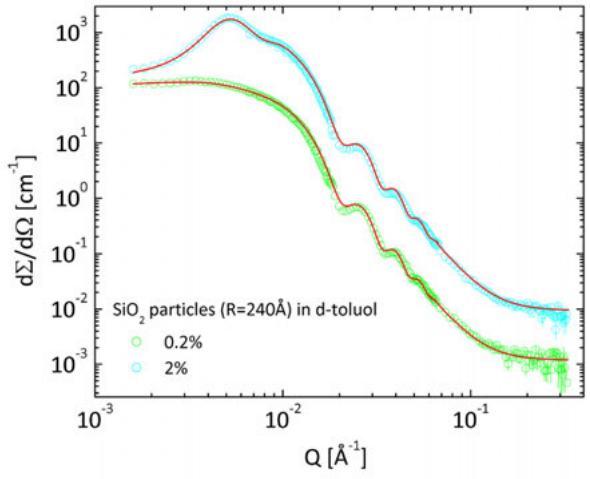


Figure 1: Scattering patterns from silica particles in d-toluol measured with 4.5 Å neutrons over the typical Q-range at KWS-2. The fitting curves include the form factor and the structure factor of the particles as well as the instrumental resolution.

The high neutron flux allows for an optimal use of the high-resolution mode: aspherical MgF_2 lenses in combination with a high-resolution detector enable smallest Q vectors in the range of 10^{-4} $Å^{-1}$. The disc chopper reduces the wave length band width to 1% and, therefore, reduces the chromatic aberration.

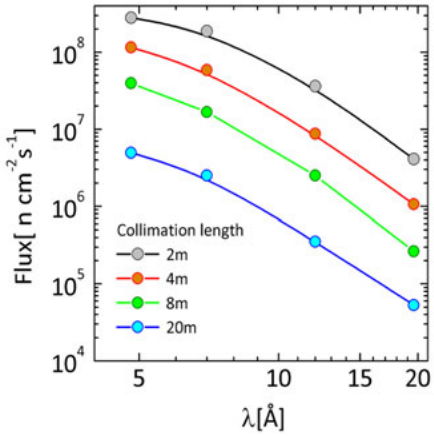


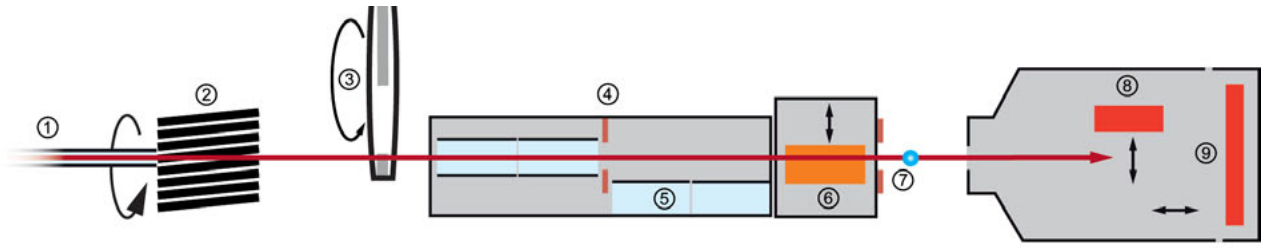
Figure 2: The neutron flux at the sample position of KWS-2 acquired for 13 l CNS filling (nominal filling: 15 l).

Typical Applications

- Colloids
- Polymer blends, diblock copolymers
- Nanocomposites
- Microemulsions, complex fluids, micelles
- Protein structure, membranes
- Kinetics of demixing, micelle formation, aggregation
- Shear induced ordering of complex fluids
- Shear induced micelle deformation, rubber network deformation, nanocomposite ordering
- Pressure induced unfolding/folding of proteins
- Pressure dependence of phase diagrams, fluctuations, molecular interactions

One topic of a current interest is that of the fast kinetics of chain exchange between polymeric micelles in solution. This process can be understood by following the time evolution of the scattered intensity (fig. 3), when differently labeled polymers (fully deuterated and fully protonated) are mixed (t = 0s) in an isotopic solvent mixture with a scattering length density exactly matching the average of the two polymers [2].

[1] A.Radulescu and A.Ioffe, Nucl. Inst. Meth. A, 586 (2008) 55.
[2] L.Willner et al., Europhys.Lett. 55 (2001) 667



Sample Environment

- Rheometer shear sandwich
- Rheowis-fluid rheometer (max. shear rate 10000 s^{-1})
- Anton-Paar fluid rheometer
- Stopped flow cell
- Sample holders: 9 horizontal x 3 vertical (temperature controlled) for standard Hellma cells 404.000-QX, and 110-QX
- Oil & water thermostats (typical 10..100°C)
- Electric thermostat (RT..200°C)
- 6-positions thermostated (Peltier) sample holder (-40°C..150°C)
- Magnet (horizontal, vertical)
- Cryostat with sapphire windows
- High temperature furnace
- Pressure cells (500 bar, 2000 bar, 5000 bar)

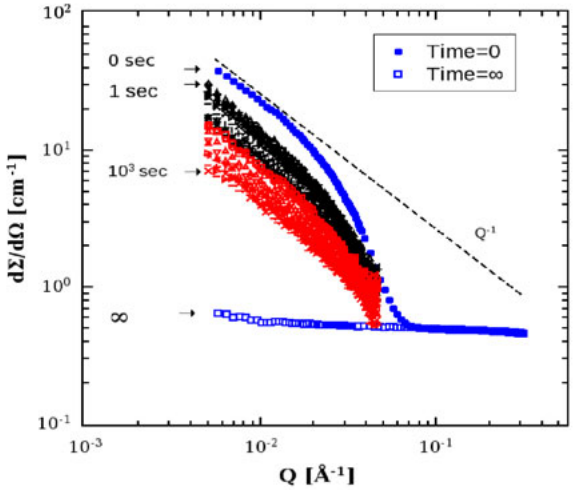


Figure 3: Time-resolved SANS (1s time resolution) of fast chain exchange under equilibrium between PEP(1k)-PEO(1k) cylindrical micelles using a stopped-flow apparatus at KWS-2

Technical Data

Overall performance

Q = 0.0007..0.5 $Å^{-1}$
Maximal flux: 3 x 10^8 $n/cm^2/s$
Typical flux: 8 x 10^6 $n/cm^2/s$
(collimation 8 m, aperture 30 x 30 mm^2, λ = 7 Å)

Velocity selector

Dornier, FWHM 20 %, λ = 4.5 Å – 12 Å, 20 Å

Chopper

for TOF-wavelength analysis, FWHM 1 %

Active apertures

2 m, 4 m, 8 m, 14 m, 20 m

Aperture sizes

rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Sample aperture

rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Neutron lenses

MgF_2, diameter 50mm, curvature 20mm
Packs with 4, 6,16 lenses

Sample stage

XYZθ translational-rotational stage
Accuracy better than 0.01°, 0.01mm

Detector 1

Detection range: continuous 1 m – 20 m
^{6}Li-Scintillator 1 mm thickness + Photomultiplier
Efficiency better than 95 %, Spatial resolution 5.3 x 5.3 mm^2, 128 x 128 channels
Max. countrate 0.6 MHz (τ_{dead} = 0.64 µs)

Detector 2 (high res.)

Spatial resolution 0.45 x 0.45 mm^2
Active area: Ø = 8.7 cm
^{6}Li-Scintillator 1 mm thickness
Fixed position: 17 m after sample position

Dr. Aurel Radulescu

Phone: +49.(0)89.289.10712
Email: a.radulescu@fz-juelich.de

Phone Instrument: .14326

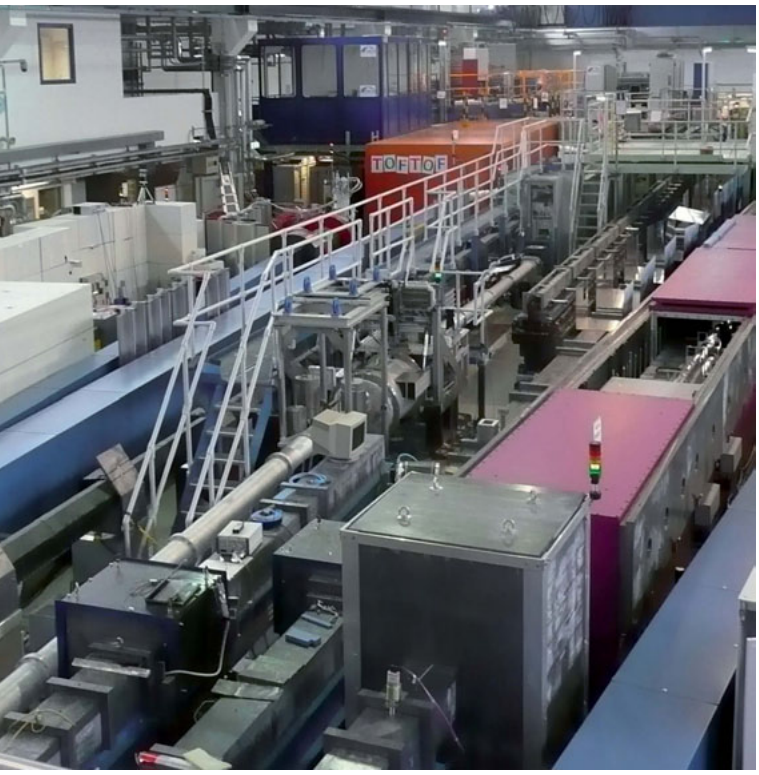
Dr. Vitaly Pipich

Phone: +49.(0)89.289.10710
Email: v.pipich@fz-juelich.de

www.jcns.info/jcns_kws2

KWS-3

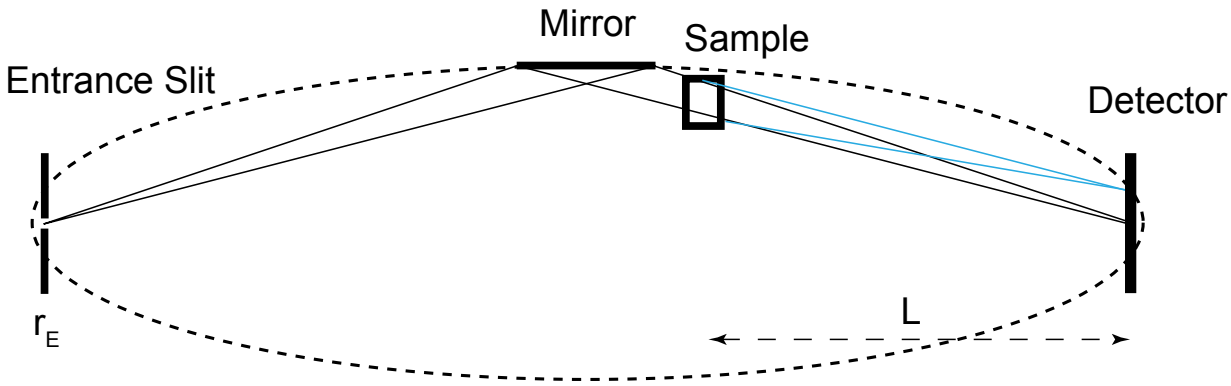
very small angle scattering diffractometer



Description

KWS-3 is a very small angle neutron scattering experiment running on the focusing mirror principle with a wave vector transfer resolution between 10^{-4} and 10^{-3} Å^{-1}, bridging a gap between Bonse-Hart and pinhole cameras. After the transfer into the guide hall of the FRM II neutron source in Garching a major upgrade became necessary, with the aim to make proper use of the enhanced neutron flux, which is larger by a factor of 7. Especially the neutron mirror was refurbished with a new ^{65}Cu-coating. A second sample chamber at the distance of 1 m allows the extension of the Q-range up to $3.5 \cdot 10^{-2}$ Å^{-1} giving proper overlap to the Q-range of the other SANS machines at FRM II. After mirror refurbishment and optical alignment the upgrade activities are going on at the end of the dedicated neutron guide.

The principle of this instrument is a one-to-one image of an entrance aperture onto a 2D position-sensitive detector by neutron reflection from a double-focusing elliptical mirror. It permits to perform SANS studies with a scattering wave vector resolution between 10^{-4} and 10^{-3} Å^{-1} with considerable intensity advantages over conventional pinhole-SANS and Double Crystal Diffractometers. Therefore it perfectly bridges the “Q-gap” between U-SANS and SANS: Very Small Angle Scattering (V-SANS).

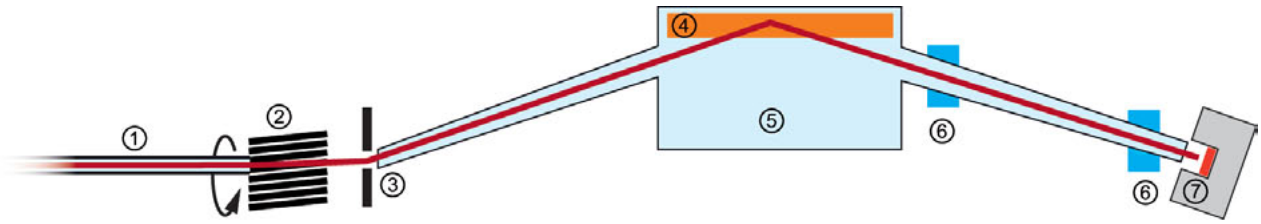


$$\lambda = 12\ \text{Å}$$

$$\delta Q = \frac{k \cdot r_E}{L} \qquad \left(k = \frac{2\pi}{\lambda}\right)$$

$$\left.\begin{array}{l} k = 0.5\ \text{Å}^{-1} \\ r_E = 2\ \text{mm} \\ L = 10\text{m} \end{array}\right\} \longrightarrow \delta Q = 10^{-4}\ \text{Å}^{-1}$$

Figure 1: Principle of KWS-3 - superior flux of focusing optics in the resolution regime at very low $Q \leq 10^{-2}$ Å^{-1} compared to pinhole geometry. Length scales up to 1 µm are accessible.



① Neutron guide NL3a
② Velocity selector
③ Entrance aperture
④ Toroidal mirror
⑤ Mirror chamber
⑥ Sample positions
⑦ Detector

Typical Applications:

- Bridge between bonse-hart and conventional SANS
- Materials science
- Hierarchical structures
- Multilamellar vesicles
- Super structures of nanocomposites, colloids, polymers

The instrument covers the Q range of small angle light scattering instruments. Especially when samples are turbid due to multiple light scattering, V-SANS gives access to the structural investigation. Thus, the samples do not need to be diluted. The contrast variation method allows for highlighting of particular components.
In figure 2 the V-SANS (Very Small-Angle Neutron Scattering) measurement of an ordered polymer (PMMA) with a radius of 776 nm is depicted. The spherically shaped polymer particles with a diameter of about 1.5 µm causes rings of scattered neutron intensity around the beam centre. The very high scattering intensities caused by the primary beam in the centre of the rings are not depicted on the full scale.

Technical Data

Overall performance

- Resolution:
  $\delta Q = 10^{-4}$ Å^{-1} (extension to $4 \cdot 10^{-5}$ Å^{-1} possible)
- Q-range:
  $1.6 \cdot 10^{-4} – 3.5 \cdot 10^{-3}$ Å^{-1} at 10 m distance
  $1.6 \cdot 10^{-3} – 3.5 \cdot 10^{-2}$ Å^{-1} at 1 m distance
- Neutron flux (focus) 5000 n/sec

Velocity selector

- MgLi
- $\Delta\lambda/\lambda = 0.2$
- $\lambda = 12$ Å (24 Å with low flux)

Aperture size (focus)

2×2 mm^2 – 5×5 mm^2

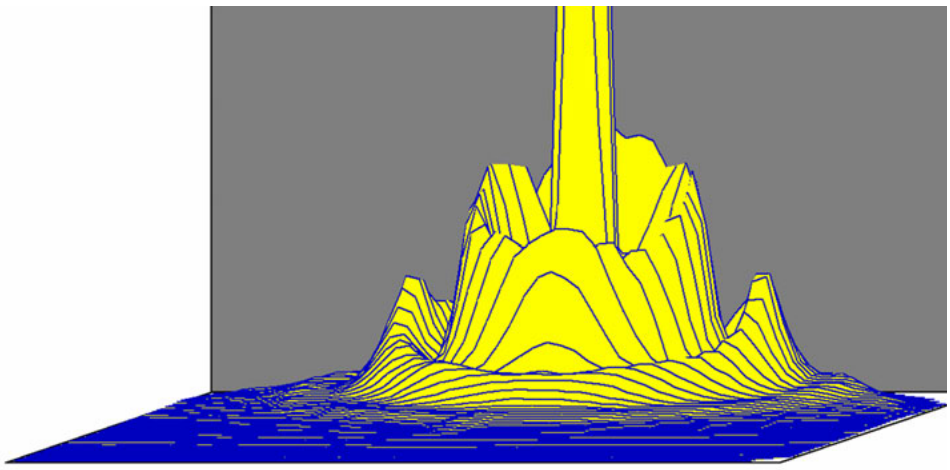


Figure 2: Three-dimensional plot of the neutron intensity scattered by ordered PMMA-colloids with a diameter of 1.5 µm. The very high intensity contributions in the centre are caused by the primary beam.

Dr. Günter Goerigk

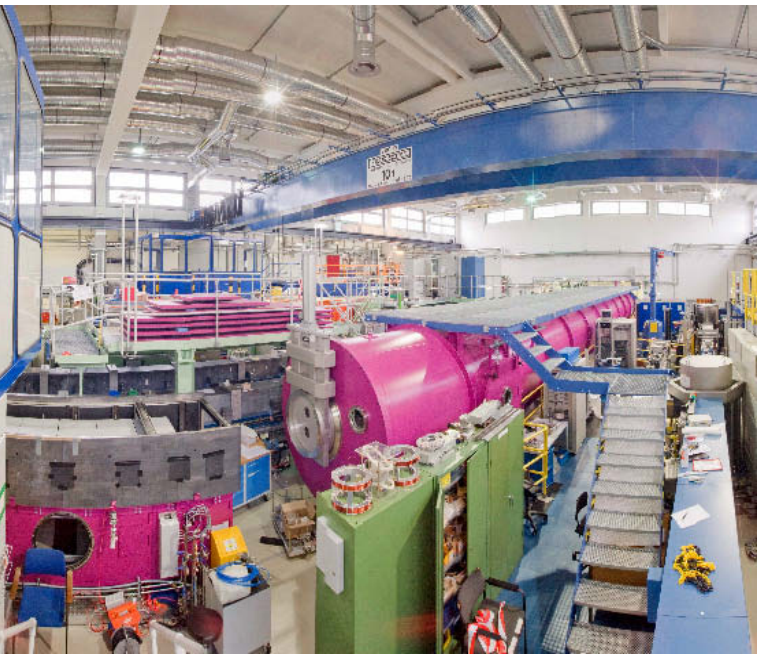
Phone: +49.(0)89.289.10746
Email: g.goerigk@fz-juelich.de

Phone Instrument: .14325

www.jncs.info/jcns_kws3

SANS-1

small angle neutron scattering



Description

The new small angle scattering instrument SANS-1, a project of the Technische Universität München (TUM) and the Helmholtz-Zentrum Geesthacht (formerly known as GKSS-Forschungszentrum), is currently built at the Forschungs-Neutronenquelle Heinz Maier-Leibnitz, FRM II.
To optimise the SANS-1 instrument claiming to be at the "state of the art", many calculations and variations of instrument parameters were performed by Monte Carlo simulations in advance. Results of these simulations [2] are a vertical S-shaped neutron guide with extreme suppression of fast background neutrons optimised for complementary wavelength packages, a tower with two eligible selectors, one for medium resolution at high intensity and one for high resolution (optional), two optimised Fe/Si transmission polarizers and two area detectors.
After passing the selector tower, a collimation system with four parallel horizontal tracks is installed. One track is occupied with a neutron guide, another one with apertures for improving resolution, one position is for a laser system to support alignment and the last one is equipped with background apertures and could be used for lenses. The detector tube of around 2.4 m inner diameter allows to use an area detector of 1 × 1 m^2 with lateral movement of more than 0.5 m. The detector is equipped with 128 position sensitive detectors to provide 8 mm × 8 mm pixel resolution. The second detector of 0.5 × 0.5 m^2 is for longer distances and achieves a resolution of 3 mm.
It is planned to install a chopper system to enhance the dynamic Q-range and flexible wavelength resolution.

Typical Applications

The instrument SANS-1 is dedicated to study the structure of material on length scale of 10 to 3000 Å. In particular, SANS is used to study the shapes and sizes of the particles dispersed in homogeneous medium. It involves scattering of a monochromatic beam of neutrons from the sample and measuring the scattered neutron intensity as a function of the scattering angle.
The technique provides valuable information over a wide variety of scientific and technological applications including

- Precipitates in alloys
- Chemical aggregation,
- Defects in materials, surfactants, colloids,
- Ferromagnetic correlations in magnetism,
- Alloy segregation,
- Polymers, proteins, biological membranes, viruses, ribosomes and macromolecules.

[1] R. Gilles et al., Physica B, 385 386 (2006), 1174-1176.
[2] R. Gilles et al., J. Appl. Cryst., 40 (2007), s428-s432.

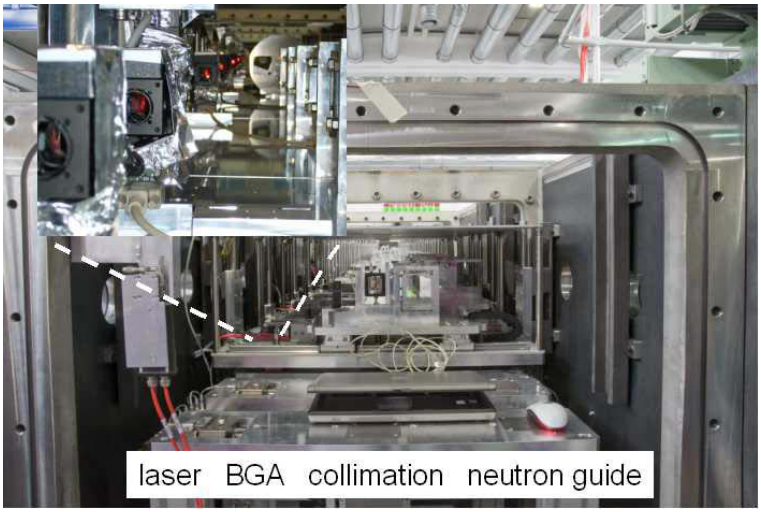
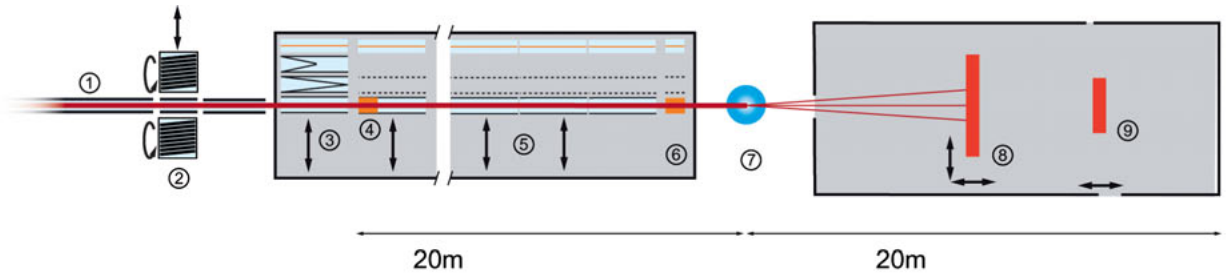


Figure 1: View into the collimation chamber of the SANS-1.

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

Technische Universität München



① Neutron guide NL4a
② Velocity selector 1+2
③ Changeable polarizers
④ Spin flipper
⑤ 4 collimation sections 20 m
(neutron guide, collimation slits, laser beam)
⑥ Focusing lenses
⑦ Sample position
⑧ Position sensitive area detector (1 x 1 m²)
⑨ High resolution position-sensitive area detector (0.5 x0.5 m²)

Sample Environment

- High temperature furnace
- Deformation-rig with heating
- Magnet (horizontal and vertical)
- Sample changer with thermostat
- Cryostat

Laser System

A redundant laser alignment system to position in the neutron guide, the collimation, the background apertures (BGA) or the laser in the neutron beam is installed. In addition the laser is used to support the positioning of the sample (including the sample environment) or the beam stop in a proper way.

Technical Data

Primary beam

- S-shaped neutron guide (NL 4a), 50 mm × 50 mm
- Mechanical velocity selectors with variable speed
  1) $\Delta\lambda/\lambda$ = 10 % medium resolution
  2) $\Delta\lambda/\lambda$ = 6 % high resolution
- Planned in future: chopper system with $\Delta\lambda/\lambda$ = 1 %
- Wavelength range: 3.5 Å – 30 Å
- Wavelength resolution: 1 % - 25 % (FWHM)

Polarization

- Two V-shaped polarizers

Source-to-sample distance

- 1 m, 2 m, 4 m, 8 m, 12 m, 16 m to 20 m in steps via insertion of neutron guide sections except 1 m

Sample size

- 0 to 50 mm diameter

Q-range

- theoretical 0.0001 $Å^{-1} < Q < 2 Å^{-1}$

Detectors

1) 128 ^{3}He position-sensitive proportional counter with 1000 mm × 1020 mm^2 total area and 8 mm resolution and lateral detector movement up to 0.5 m, counting rate up 1 MHz
2) Detector with better resolution of 3 mm and 0.5 m × 0.5 m total area at long distances.

Dr. habil. Ralph Gilles

Phone: +49.(0)89.289.14665
Email: ralph.gilles@frm2.tum.de

Phone Instrument: .12818 / .14992

Dr. André Heinemann

Phone: +49.(0)89.289.14534
Email: andre.heinemann@hzg.de

www.frm2.tum.de/sans-1

REFSANS

reflectometer and evanescent wave small angle neutron spectrometer

Description

The horizontal reflectometer REFSANS has been designed to enable specular reflectometry as well as Grazing Incidence Neutron Scattering studies of both solid samples and liquid-air interfaces.
By using a polychromatic incident neutron beam and time of flight (TOF) wavelength resolution, REFSANS gives simple access to a large Q range. Typical reflectometry curves are recorded using three incident angles to cover the 0 – 2 nm^{-1} Q_z domain. In the case of GISANS, the TOF mode provides direct information about the full penetration curve from a single incident angle.
The instrument versatility relies on one hand on the fact that the wavelength resolution can be tuned between 0.2% and 10%, on the other hand on the possibility to independently control the horizontal and vertical divergence by means of a complex optics. These two characteristics make it possible to optimally perform reflectometry and GISANS. One can easily switch between these two configurations for a given sample and thereby fully investigate its structure without having to alter externally applied fields or constraints (temperature, chemical environment).
For reflectometry, an horizontally smeared out beam of up to 80 mm width is used in order to maximize intensity. For GISANS, up to 13 point beams are impinging on the sample and point focused on the 2D position sensitive detector placed at a distance of 9 m (see collimation scheme in fig. 1). This setup allows to resolve lateral structures with dimensions up to several micrometer. In all other cases the detector can be placed at any distance between 1.5 m and 12 m from the sample, thereby making it easy to control the explored angular range and optimize the resolution-background intensity trade-off.

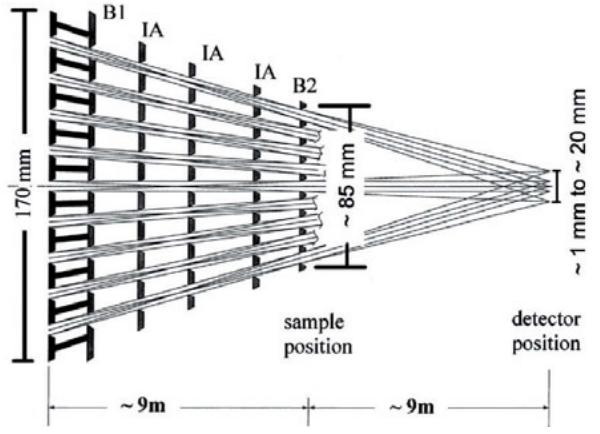


Figure 1: The GISANS focusing channels (used in NGE3 and 4).

Typical Applications

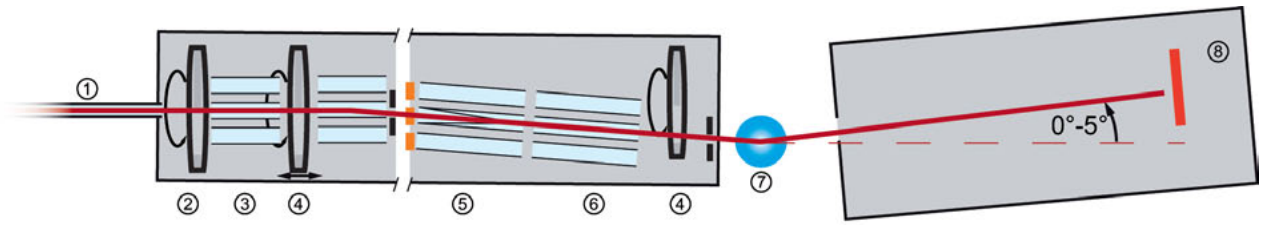
The TOF reflectometry and GISANS techniques can be used to characterize thin films in general. Reflectometry provides information about the structure along the sample's normal, while GISANS gathers information about the in-plane correlations. Typical reflectometry experiments include:

- Characterization of polymer thin film structure and their swelling behavior in presence of various vapors.
- Biological systems such as solid or liquid supported membranes (e.g determination of the morphology and localization of proteins at interfaces) - see figure 2
- Metallic multilayers (e.g magnetically active films)
- Coatings

GISANS complements these measurements and has been successfully applied to polymer thin films (lateral correlations e.g in dewetted systems, detection and identification of polymer lamellae in immiscible blends or semicristalline systems), composites, nanopatterned metallic surfaces for which Bragg truncation rods have been reconstructed (see figure 3).

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

Bundesministerium für Bildung und Forschung



① Neutron guide NL 2b
② Master chopper
③ Neutron guide elements
④ Slave chopper 1+2
⑤ Changeable polarizer
⑥ Neutron guide elements
⑦ Sample position
⑧ Detector

Sample Environment

The optimal sample size is 70 × 70 mm². Various environments are available:

- Simple sample changer for three substrates,
- Vibration controlled Langmuir trough for liquid-air interfaces studies,
- Magnetic fields up to 7 Tesla,
- Cryostats

A heavy load Huber goniometer (max load 200 kg) is normally used to carry the experimental setup, but it can easily be removed and replaced by custom equipments.

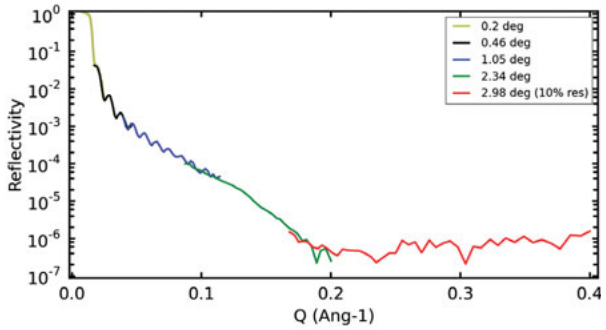


Figure 2: Typical reflectivity curve. Obtained for a biological sample (POPC/POPS Phospholipid bilayer supported on Si).

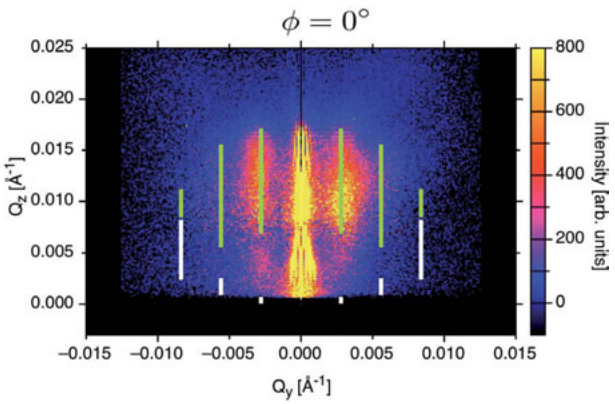


Figure 3: Bragg rods reconstructed from the GISANS pattern of a nanostructured Gd samples (horizontal wires with spacing 250 nm). The annotation marks the expected peak positions.

Technical Data

Primary beam

- Neutron guide NL 2b
- Astrium choppers with wavelength resolution to be chosen in the range 0.2% – 10% for wavelengths in the range 2 Å – 20 Å. Rotation speed up to 6000 rpm.
- Collimation: 2 vertical adjustable slits (0 – 12 mm) separated by 8.68 m
- For reflectometry, the horizontal divergence is maximized by use of supermirrors (m = 2 – 3)

Flux at sample

Typical values (ΔQ / Q = 3 %):

- 1 ·10⁴ n/s (incident angle 0.2°)
- 3 ·10⁶ n/s (at 2.5°)

in the wavelength range 2 to 6 Å for a 60 × 60 mm² sample.

Accessible Q-range

- Reflectometry:
  Q_z up to .0.3 Å^{-1} for reflectivities down to the 10^{-7} range.
- GISANS:
  Q_y = 9.5 ·10^{-5} Å^{-1} to 0.18 Å^{-1} (corresponding to distances from 6 µm down to 3.5 nm)

Detector

High performance 2D 500 × 500 mm² multiwire ^{3}He detector (pixel size 2.7mm, efficiency 80% at 7 Å, gamma sensitivity < 10^{-6}) positioned between 1.5 m and 12 m from the sample. The detector is installed in a liftable vacuum tube in order to reach exit angles up to 6 degrees at the maximum distance.

TOF analysis

The data are acquired in list mode, each neutron arrival time and impact position being stored for later analysis. This makes it possible to perform various rebinnings in order to tune the resolution/ intensity tradeoff.

Dr. Jean-François Moulin

Phone: +49.(0)89.289.10762
Email: jean-francois.moulin@hzg.de

Phone Instrument: .14880

Reinhard Kampmann

Phone: +49.(0)89.289.10764
Email: Reinhard.kampmann@hzg.de

www.frm2.tum.de/refsans

N-REX+

neutron reflectometer with X-ray option

Typical Applications

The instrument is designed to perform a variety of experiments, e.g.:

- Specular and off-specular neutron reflectivity measurements on surfaces, interfaces and thin film systems
- Large-angle grazing incidence / evanescent wave diffraction
- Polarized neutron experiments with four-channel polarization analysis and wide-angle spin analysis
- Neutron / X-ray contrast experiments
- Spin-echo resolved grazing incidence neutron scattering (SERGIS)

Description

The neutron reflectometer N-REX+ is designed for the determination of structural and magnetic properties of surfaces, interfaces and thin film systems. It is operated by the Max Planck Society. First regular user experiments have been conducted in 2007.

The instrument is an angle-dispersive fixed-wavelength machine; the default wavelength is 4.3 Å. The default sample surface orientation is horizontal, but experiments with vertical sample orientation can also be performed with certain restrictions. Depending on sample requirements, the direct beam can be reflected upward or downward. Both unpolarized and polarized experiments can be conducted. In polarized mode, full 4-channel polarisation analysis is provided, along with wide-angle spin analysis (e.g. by means of polarized ^{3}He cells). Magnetic fields up to 7.5 Tesla and cryogenic temperatures below 1 K can be provided. Large and heavy sample environments up to 440 mm diameter and 400 kg weight can be accomodated. In addition to specular and off-specular reflectivity measurements, large angle grazing incidence experiments are also possible. Optionally, neutron experiments can be combined in-situ with X-ray reflectivity experiments. Furthermore, spin-echo resolved grazing incidence scattering (SERGIS) experiments are possible.

The instrument control software is based on Labview (National Instruments) and SPEC (**www.certif.com**). Data processing is normally done with yorick (**yorick.sourceforge.net**), and the data can be provided to the user in any desired format. For the analysis of polarized neutron data, the superfit fitting program is available.

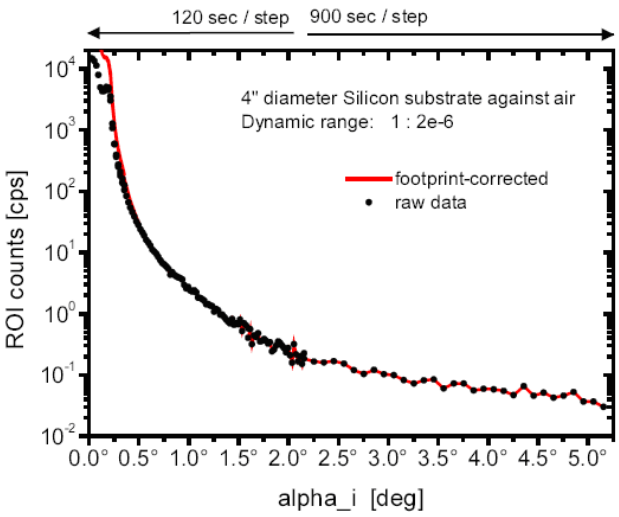
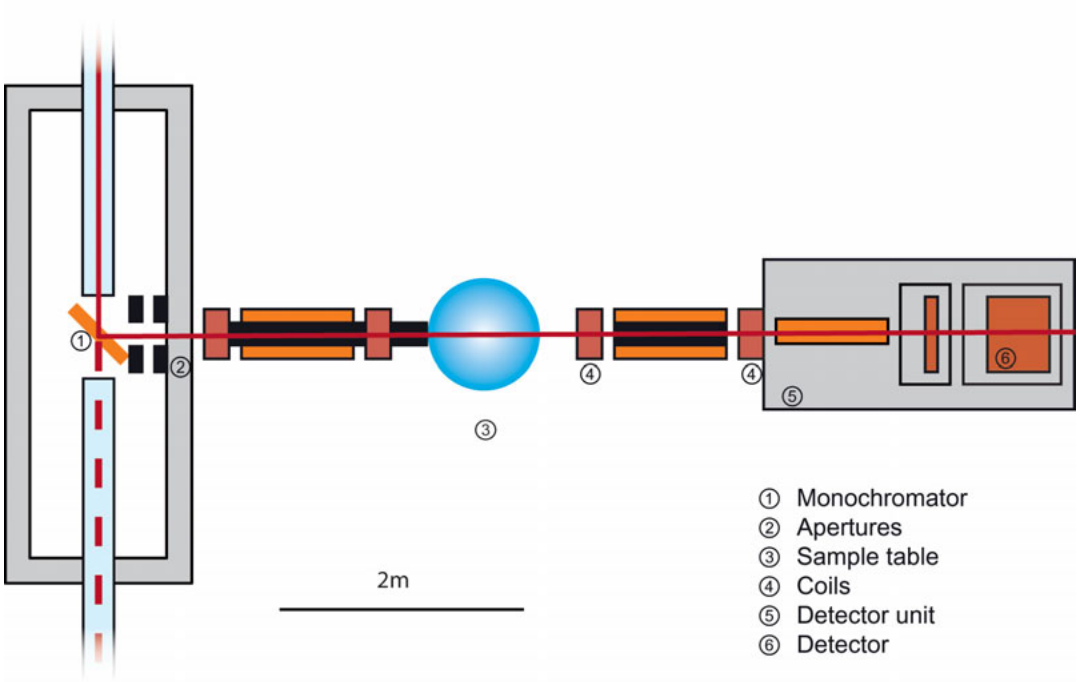


Figure 1: Reflectivity data from a 100 mm diameter silicon wafer measured in air show a dynamic range of 10^{-6} in the reflectivity data. The same data quality can also be reached on considerably smaller samples. In polarized mode, a dynamic range of 10^{-5} to 10^{-6} can be achieved for 1 cm^2 surface area.

Sample Environment

FRM II standard sample environment can be used with N-REX+.
Further instrument specific equipment:

- Sample chambers for high-vacuum and gas athmosphere (25 - 300 °C)
- Solid-liquid sample cell (with closed cycle thermostat)
- Magnetic fields up to 2 Tesla
- Cryostat
- Add-on X-ray reflectometer



Technical Data

Monochromator

Type:	HOPG (002)
Focussing:	horizontal
Wavelength:	2Å – 5.5 Å
Wavelength resolution:	1 % – 4 %
Wavelength filter:	cooled Be

Collimation

Vertical sample slit opening:	0.2 – 6 mm
Horizontal sample slit opening:	0.2 – 100 mm
Vertical beam divergence:	0.01° – 0.2°
Horizontal beam divergence:	0.01° – 5°
Monochromator to sample distance:	2.5 m

Polarization

Beam polarization:	~ 98 %
Polarization efficiency:	~ 98 %
	(depending on spin analysis device)
Flipper efficiencies:	100 %

Detector

Single detector:	^{3}He tube
2D area detector:	^{3}He wire chamber (Gabriel type)
2D detector size:	190 mm × 190 mm
2D detector resolution:	3 mm
Detector to sample distance:	2465 mm
Max. detector arm inclination angle:	-5.5° – +15°

Measurement ranges and resolution

Reflectivity dynamic range:	better than $1{:}1{\cdot}10^{-6}$
Max. momentum transfer:	0.8 Å^{-1}
Optimum q_z-resolution:	$2 \cdot 10^{-4}$ Å^{-1}
Max. GID in-plane momentum transfer:	5.1 Å^{-1}

Dr. Adrian Rühm

Phone: +49.(0)89.289.12184
Email: ruehm@mf.mpg.de

Phone Instrument: .14878

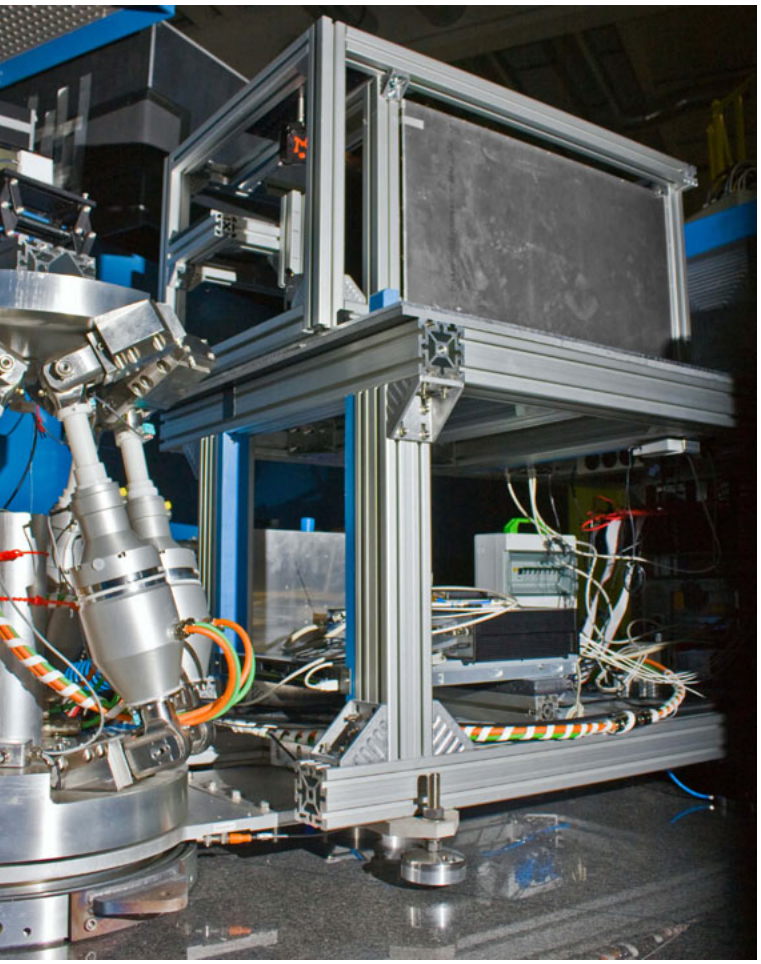
Dr. Thomas Keller

Phone: +49.(0)89.289.12164
Email: thomas.keller@fkf.mpg.de

www.frm2.tum.de/nrex

MARIA

magnetic reflectometer with high incident angle



Description

The neutron reflectometer MARIA with polarization analysis has been designed for the investigation of thin magnetic layered structures down to the monolayer scale and lateral structures. The reflection of polarised neutrons allows to determine individually the density and the modulus and the direction of the magnetisation vector of buried layers.

MARIA is optimised for layer thicknesses between 3 – 300 Å and lateral structure sizes from nm to µm sizes. Consequently the instrument is designed for small focused beam and sample sizes of 1 cm^2 at λ=4.5 Å (available: 4.5 Å < λ < 40 Å) in a vertical orientation with a maximum incident angle of 180° and outgoing angle ranging from -14° to 100°. Maria provides polarisation analysis in standard operation, where the beam is polarised by a polarising guide (z-geometry; 4.5 Å < λ < 10 Å) and analysed by a wide angle ^{3}He-cell.
Beside the above described reflectometer mode with good resolution in the horizontal scattering plane, MARIA can be used in the GISANS mode with additional resolution in the vertical direction. The latter mode allows one to measure lateral structures down to the nm scale.

At the sample position a Hexapod with an additional turntable (360°) is installed, which can take a load up to 500kg. In the standard configuration magnetic fields are provided up to 1.3 Tesla (Bruker electromagnet) and cryogenic temperatures down to 4K (He closed cycle Cryostat). Beside this standard setup the complete sample environment of the JCNS can be adopted to MARIA so that magnetic fields up to 5 T and temperatures from 50 mK to 500 K are available.

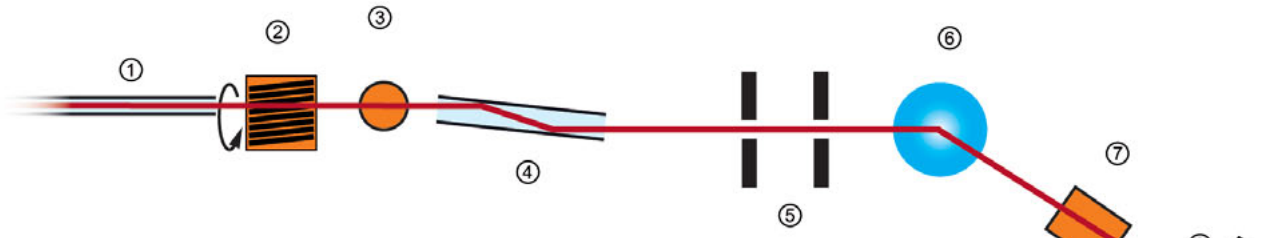
All parts of MARIA are controlled by a computer system according to the “Jülich-Munich” standard based on a Linux workstation. This allows a flexible remote control with automatic scan programs, including the control of sample environment as cryostat and electromagnet.

Typical Applications

With scattering under grazing incidence we investigate depth-resolved the laterally-averaged magnetizations and the correlations between their lateral fluctuations. With an additionally polarized neutron beam we derive a vector information on the laterally-averaged magnetization (reflectivity) and on the correlations between their lateral fluctuations (off-specular scattering - µm length scale, GISANS – nm length scale).

In general MARIA can be used for measurements of magnetic roughness, the formation of magnetic domains in thin layered structures, lateral structures, etc. (polarized mode) and density profiles, structures of solid polymer layers, etc. (unpolarized mode with higher intensity).
Furthermore possible without the need for multilayers investigation of:

- Diluted semi conducters
- Influence of the substrate
- Interfaces between oxide materials



① Neutron Guide NL5-N
② Velocity selector
③ Fermi chopper
④ Polarizer
⑤ Slit pair
⑥ Hexapod sample table
⑦ Polarization analyzer (^{3}He)
⑧ Detector

Sample Environment

The optimal sample size for MARIA is 10 × 10 mm^0 with the following parameters:

- Thin magnetic layers down to sub mono layers
- Polarization analysis as standard
- Layer thickness of 1 – 300 Å optimized, but – 1000 Å (multi layers) should be feasible
- Lateral structures of nm to µm

Besides the described cryogenic temperatures and magnetic fields MARIA can provide a fully equipped Oxid-MBE (Molecular Beam Epitaxy) to the user. The typical sample sizes are 10 × 10 mm^2 and as targets we can provide Al, Cr, Pr, Fe, La, Nb, Ag, Nd, Tb, Sr, Mn, Ti and Co.

Technical Data

Primary beam

- Neutron guide NL5-N
  vertically focussing elliptic guide
- Monochromator: Velocity selector
- Wavelength:
  4.5 Å – 10 Å (polarized)
  4.5 Å – 40 Å (unpolarized)
- Resolution:
  10% velocity selector
  1%, 3% Fermi chopper
- Double reflection polarizer
- Horizontal scattering plane

Flux at sample

- Expected pol. flux 5 · 10^7 n/cm^{2}s for 3mrad collimation

Distances and angles

- 4100 mm distance S1 – S2 (collimation)
- 400 mm distance S2 – sample
- 50 mm × 40 mm (w × h) max. opening S2
- 1910 mm distance sample – detector
- 120° maximum detector angle
- GISANS option: 4m collimation length

Accessible Q-range

- Reflectometry:
  Q_z- range 0.002 Å^{-1} – 3.2 Å^{-1}
  Q_x- range 6 · 10^{-5} – 0.001 Å^{-1}
  α_f -14° – 100°
- GISANS option:
  Q_y- range 0.002 Å^{-1} – 0.2 Å^{-1}

Polarization analysis

- ^{3}He cell

Detector

- 2D PSD detector
  size 400 × 400 mm^2
  resolution 2 × 3 mm (h × v)

Dr. Stefan Mattauch

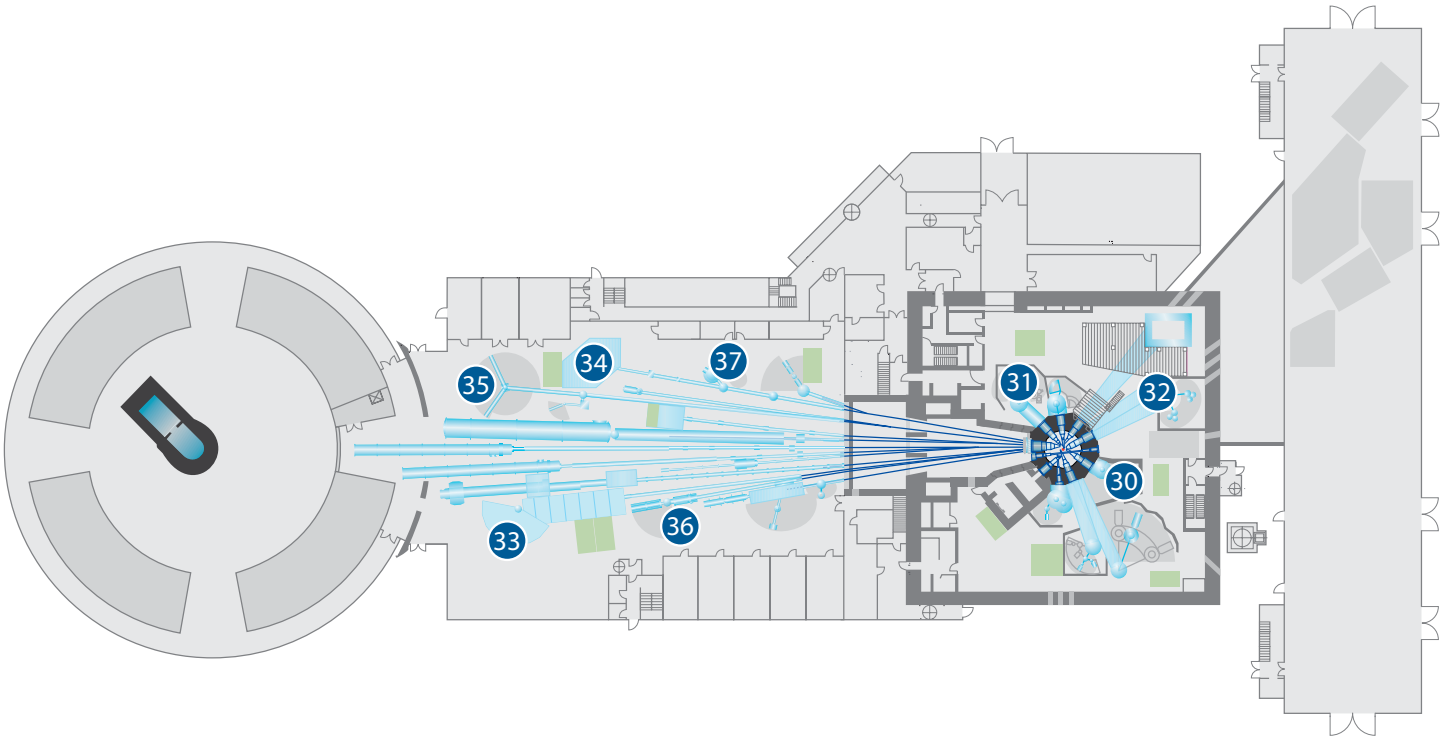
Phone: +49.(0)89.289.10709
Email: s.mattauch@fz-juelich.de

Phone Instrument: .10799

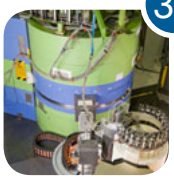
Dr. Dennis Korolkov

Phone: +49.(0)89.289.10717
Email: d.lorolkov@fz-juelich.de

www.jcns.info/jcns_maria



30
PUMA
thermal three axes
spectrometer
p. 48 / 49



31
PANDA
cold thee axes
spectrometer
p. 50 / 51

32
TRISP
three axes spin echo
spectrometer
p. 52 / 53

33
TOFTOF
cold neutron time of flight
spektrometer
p. 54 / 55

34
SPHERES
backscattering
spectrometer
p. 56 / 57

35
RESEDA
resonance spin echo
spectrometer
p. 58 / 59

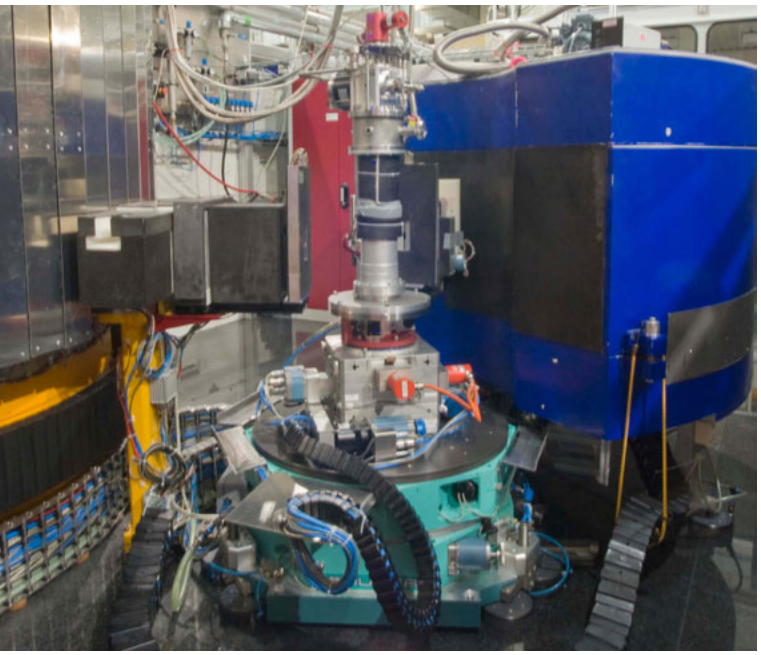
36
J-NSE
spin echo
spectrometer
p. 60 / 61

37
DNS
diffuse scattering
time of flight spectrometer
p. 62 / 63

Spectroscopy

PUMA

thermal three axes spectrometer



Description

Three axes spectrometers allow the direct measurement of the scattering function S(Q, ω) in single crystals at well defined points of the reciprocal lattice vector Q and frequency, ω and thus represent the most general instrument type.
PUMA is characterized by a very high neutron flux, as a result of the efficient use of focussing techniques. Three different vertical openings and a horizontal slit, with a maximum opening of 40 mm, define the virtual source, which is two meters before the monochromator. To reduce the contamination of the primary beam by epithermal neutrons, a sapphire filter can be placed in front of the monochromator. PUMA has a remote controlled monochromator changing unit, which allows to place one out of four different monochromators inside the drum. At present two different monochromators (PG (002) and Cu (220)) are available, covering an energy transfer up to 100 meV — Cu(111) and Ge(311) are in preparation. All monochromators are equipped with doubly focussing devices that allow for optimum focussing conditions over a wide range of incident wavevectors k_i. The horizontal divergency of the beam can be defined using a series of four Soller collimators. The two inside the monochromator drum, before and after the monochromator, can be remotely changed, whereas the two in the analyzer housing can be changed manually.
An Eularian cradle can optionally be used to access the four dimensional Q-ω-space. An innovative option of the spectrometer is the multianalyzer / detector system. It allows a unique and flexible type of multiplexing. Using this option a scattering angle range of 16° can be measured simultaneously and flexible Q-ω paths can be realized without the need to reposition the instrument. Mapping of excitations is equally well possible as kinetic single shot experiments on time scales that have not been accessible so far.
A unique feature of the instrument is the possibility to perform stroboscopic, time resolved measurements of both elastic and inelastic signals on time scales down to the microsecond regime. Using this technique, the sample is periodically perturbed by an external variable such as temperature, electric field, etc. The signal is then recorded not only as a function of momentum and energy transfer, but also given a time stamp, relative to the periodic perturbation.

Typical Applications

Phonons
- Electron / phonon interaction
- Phonon anharmocities
- Soft mode phase transitions

Magnons
- Spin waves in antiferromagnets
- Kinematic / dynamic interaction
- Electron-magnon interaction
- Unconventional superconductors
- Crystal fields

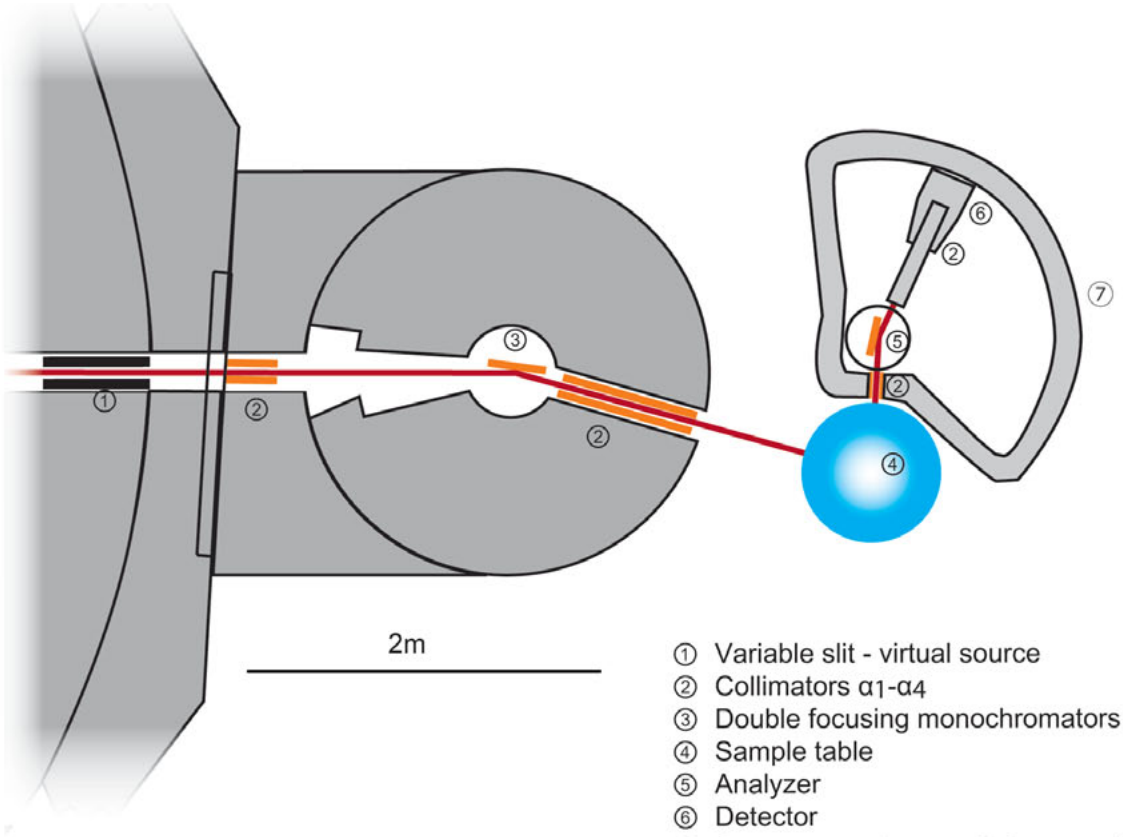
Time resolved / stroboscopic measurements
- Temperature cycling (excitations during demixing processes)
- Electrical field cycling (polarization processes in ferroelectrics)
- Temperature / pressure cycling

Diffraction; purely elastic signals
- Superstructures / satellites
- Diffuse scattering

Sample Environment

Aside from the FRM II standard sample environment the following dedicated devices are provided:
- Closed-cycle cryostates 3.5 – 300 K;
  - 650 K with adaptable heating device
- Cryofurnace 5K – 750 K
- Paris-Edinbourgh type pressure cell p < 10 GPa

Along with the detector electronics required for time resolved measurements, special sample environment for the rapid cycling is available:
- Furnace for fast temperature jumps (~ 5K/s cooling rate; < 620 K; ambient atmosphere)
- Mirror furnace (~ 5 K/s; < 1270 K; vacuum/ inert gas (Ar/ N_2) atmosphere); under development
- Switchable HV power supply (< 500 Hz; +/- 10 KV)



Technical Data

Primary beam

Beam tube SR 7 (thermal)
Beam tube entrance 140 × 90 mm²
Virtual source dimensions:
horizontal: 0 – 40 mm
vertical: (90, 110, 130 mm)

Distances

- Beam tube entrance - monochromator: 5.5 m
- Virtual source – monochromator: 2.0 m
- Monochromator – sample: 2.0 (± 0.1) m
- Sample – analyzer: 1.0 (± 0.1) m
- Analyzer – detector: 0.9 m

Collimation

Remote controlled:
- α1: 20', 40', 60'
- α2: 14', 20', 24', 30', 45', 60'

Manually changeable:
- α3: 10', 20', 30', 45', 60'
- α4: 10', 30', 45', 60'

Monochromators

Crystals: PG(002), Cu(220); size: 260 × 162 mm²
Focus vertically and horizontally adaptable to incident energy

Analyzer

PG(002); 210 × 150 mm²; vertical fixed focus; horizontally adaptable to incident energy

Sample table

- Diameter 800 mm
- Max. load 900 kg
- Amagnetic goniometer (± 15°)
- Z translation (± 20 mm)

Optional Eularian cradle

Main parameters

- Monochromator take off angle
  $-15° < 2\Theta < -115°$
- Scattering angle sample
  $-70° < 2\Theta < 120°$
  (dependent on monochromator take off angle)
- Analyzer scattering angle
  $-120° < 2\Theta < 120°$
- Incident energy range 5 meV – 160 meV
- Momentum transfer range < 12 Å^{-1}
- Energy transfer < 100 meV

Dr. Klaudia Hradil

Phone: +49.(0)89.289.14756
Email: klaudia.hradil@frm2.tum.de

Phone Instrument: .14914

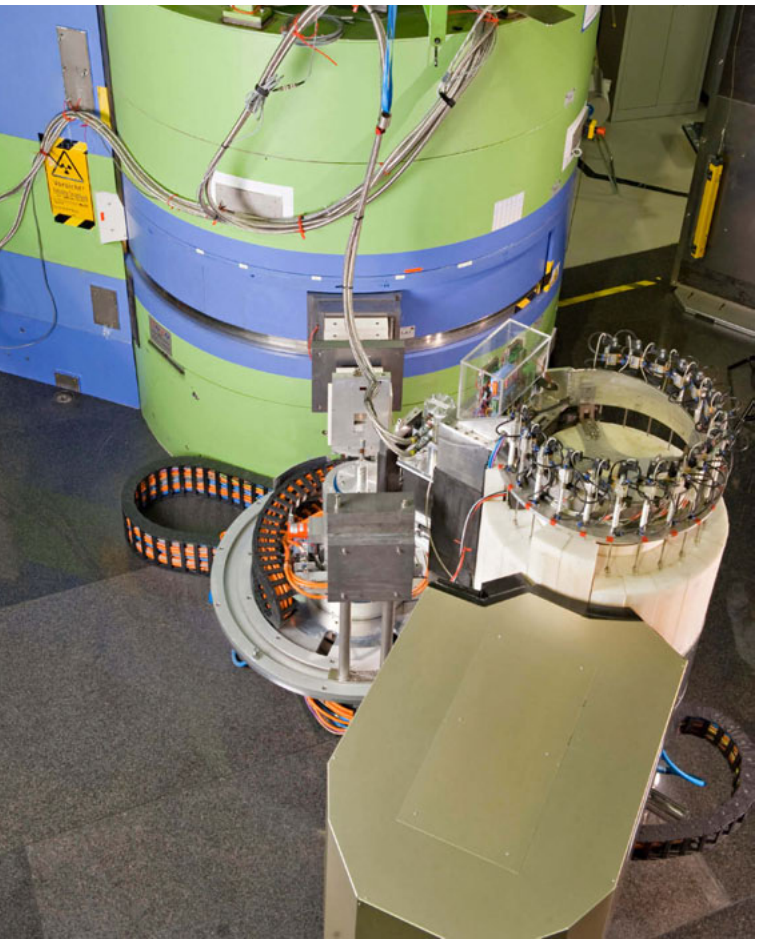
Dr. Richard Mole

Phone: +49.(0)89.289.14754
Email: richard.mole@frm2.tum.de

www.frm2.tum.de/puma

PANDA

cold three axes spectrometer



Description

The cold triple-axis spectrometer PANDA offers high neutron flux over a large dynamic range keeping the the intrumental background comparably low. PANDA is situated on the cold neutron beam-tube SR2 in the experimental hall. The high flux is achieved by neutron guide elements in the beam tube, a short source to monochromator distance and the double-focussing monochromator and analyzer crystals. Options for high energy and high q-resolution are available. With dedicated sample environments for very strong magnetic fields and very low temperatures, PANDA is ideally suited for the studies of magnetism and superconductivity on single crystals. Lattice dynamics and magnetic structures are investigated successfully, too.
A polarized neutron setup using both Heusler monochromator and analyzer and a sample-space Helmholtz-coil set for longitudinal polarization anal ysis is available.

Typical Applications

Magnetic properties
- Spin-waves
- Crystal field excitations
- Excitations in low dimensional systems
- Magnetic vs nuclear scattering

Lattice dynamics
- Phonon dispersion
- Anharmonic effects
- Polarisations vectors

General
- Critical scattering at phase transitions
- Magnon - phonon interaction
- Soft mode
- Central peak
- Diffraction:
  - without analyser: integral E method
  - with analyser:
    dE close to 0, high E & Q resolution

Sample Environment

The sample table of PANDA allows for a variety of sample environment and may easily be adapted to user specific devices. Among other PANDA disposes routinely operated sample environment for:

Low temperature
- Closed cycle cryostat (3 K < T < 300 K)
- Variox cryostat (1.5 K < T < 100 K)
- Dilution insert (50 mK < T < 6 K)

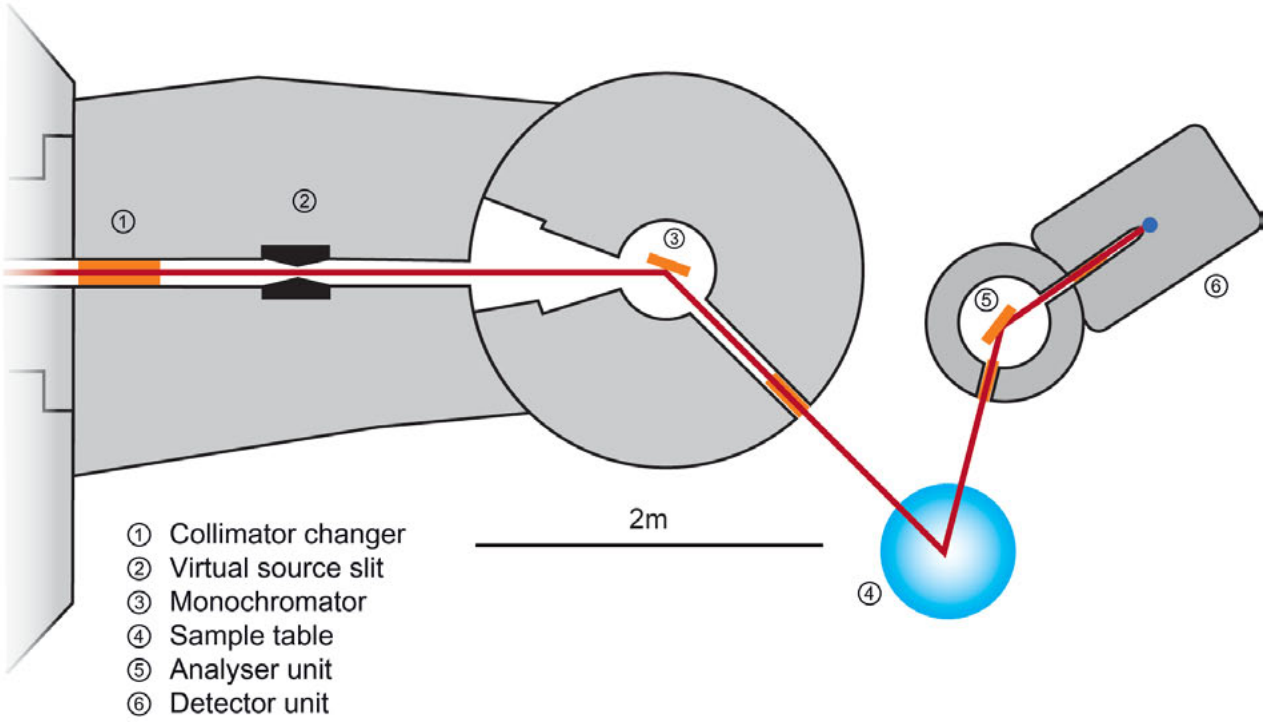
typical dimensions for sample space
Ø 50 mm, h = 70 mm

Vertical magnetic field:
- Cryomagnet V15T with optional ^{3}He dilution insert; H_{max} = 13.5 T
  (50 mK) 1.5 K < T< 100 K
  max. sample diameter: (12 mm) 19 mm
  split of coils 20 mm
- Closed-cycle magnet V7.5T
  H_{max} = 7.5 T
  Closed-cycle cryostat and high temperature furnace inserts available

High temperature
- High temperature furnace
  300 K < T < 2100 K
  sample space: Ø 50 mm, h = 50 mmr

HZB Helmholtz Zentrum Berlin

TECHNISCHE UNIVERSITÄT DRESDEN



Technical Data

Monochromators

- PG002 (d = 3.355 Å)
  $20° < 2\Theta_M < 132°$
  $1.05\ Å^{-1} < k_i < 4.0\ Å^{-1}$
  variable horizontal and vertical focussing
- Heusler (d = 3.35 Å, polarised neutrons)
  $20° < 2\Theta_M < 120°$
  $1.1\ Å^{-1} < k_i < 4.0\ Å^{-1}$
  variable vertical focussing
- Si (111) (d=3.135Å)
  $20° < 2\Theta_M < 132°$
  variable horizontal and fixed vertical focussing
  $1.15\ Å^{-1} < k_i < 4.0\ Å^{-1}$

Analysers

- PG002
  $-130° < 2\Theta_A < 100°$
  $1.05\ Å^{-1} < k_f$
  variable horizontal focussing
- Heusler (polarized neutrons)
  $-130° < 2\Theta_A < 100°$
  $1.05\ Å^{-1} < k_f$
  variable horizontal focussing

Detectors

- 1” ^{3}He tube (focussing mode)
- 2” ^{3}He tube (collimated mode))

Flux at sample

Monochromator vertically focused, horizontal flat, no collimation:

- $1.9 \cdot 10^7$ n/cm²/s for $k_i = 1.55\ Å^{-1}$ Be Filter
- $5.5 \cdot 10^7$ n/cm²/s for $k_i = 2.662\ Å^{-1}$ PG Filter

Main parameters

- Scattering angle at the sample:
  $5° < 2\Theta_S < 125°$ (moveable beam-stop)
- Energy transfer
  up to 20meV
- Momentum transfers
  up to $Q = 6\ Å^{-1}$ (depending on k_i)

Filters for higher order suppression:

- PG (l = 60 mm); $k_f = 2.57\ Å^{-1}$ or $2.662\ Å^{-1}$
- Be (closed-cycle cryostat, T ≤ 25 K);
  $k_f = 1.55\ Å^{-1}$
- BeO (liq.-N_2 cooled); $k_f = 1.33\ Å^{-1}$

Dr. Astrid Schneidewind

Phone: +49.(0)89.289.14749
Email: astrid.schneidewind@frm2.tum.de

Phone Instrument: .14869

Dr. Enrico Faulhaber

Phone: +49.(0)89.289.10767
Email: enrico.faulhaber@frm2.tum.de

www.frm2.tum.de/panda

TRISP

three axes spin echo spectrometer

Description

TRISP is a high-resolution neutron spectrometer combining the three axes and neutron resonance spin echo (NRSE) techniques. The design of TRISP is optimized for the study of intrinsic linewidths of elementary excitations (phonons, magnons) with an energy resolution in the μeV region over a broad range of momentum and energy transfers. Compared to conventional three axes spectrometers (TAS), this corresponds to an improvement of the energy resolution of one to two orders of magnitude.

TRISP also incorporates the Larmor diffraction (LD) technique, which allows to measure lattice spacings with a relative resolution $\Delta d/d = 1.5 \cdot 10^{-6}$., i.e. one to two orders of magnitude better than conventional neutron or X-ray diffraction. Absolute d-values can be determined by calibrating the instrument against an Si standard. The main applications of LD include thermal expansion under pressure and low or high temperature, and distributions of lattice constants (second order stresses). LD thus is unique in a parameter region, where standard methods such as dilatometry fail.

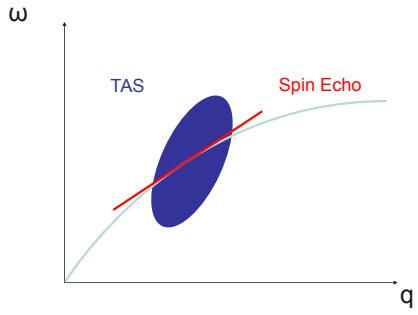


Figure 1: Measurement of the linewidth of a dispersive excitation at TRISP: The TAS background spectrometer defines a resolution ellipsoid in the (q, ω)-space (blue ellipse), the spin-echo enhances the energy resolution within the resolution ellipsoid. Tuning of the spin-echo resolution (red line) to the group velocity of excitations is achieved by rotating the RF spin flip coils. A detailed analysis of the resolution properties is given by K. Habicht et al., J. Appl. Cryst. 36, 1307 (2003).

Typical Applications

- Measurement of the intrinsic linewidths of phonons (fig. 2)
- Measurement of the instrinsic linewidths spin excitations (fig. 3).
- Larmor diffraction is used to determine thermal expansion and second order stresses under pressure and at low or high temperature (fig 4).

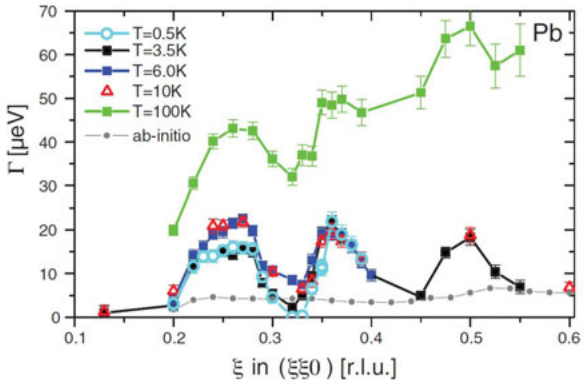


Figure 2: Linewidths of transverse acoustic phonons along q = (ξ, ξ , 0) in Pb at selected temperatures. Several anomalies are visible, which are not predicted by state-of-the-art ab initio calculations (gray symbols). (P. Aynajian et al., Science 319, 1510 (2008)).

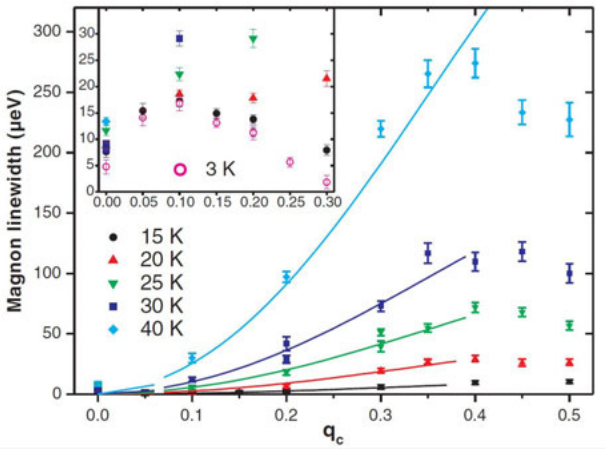
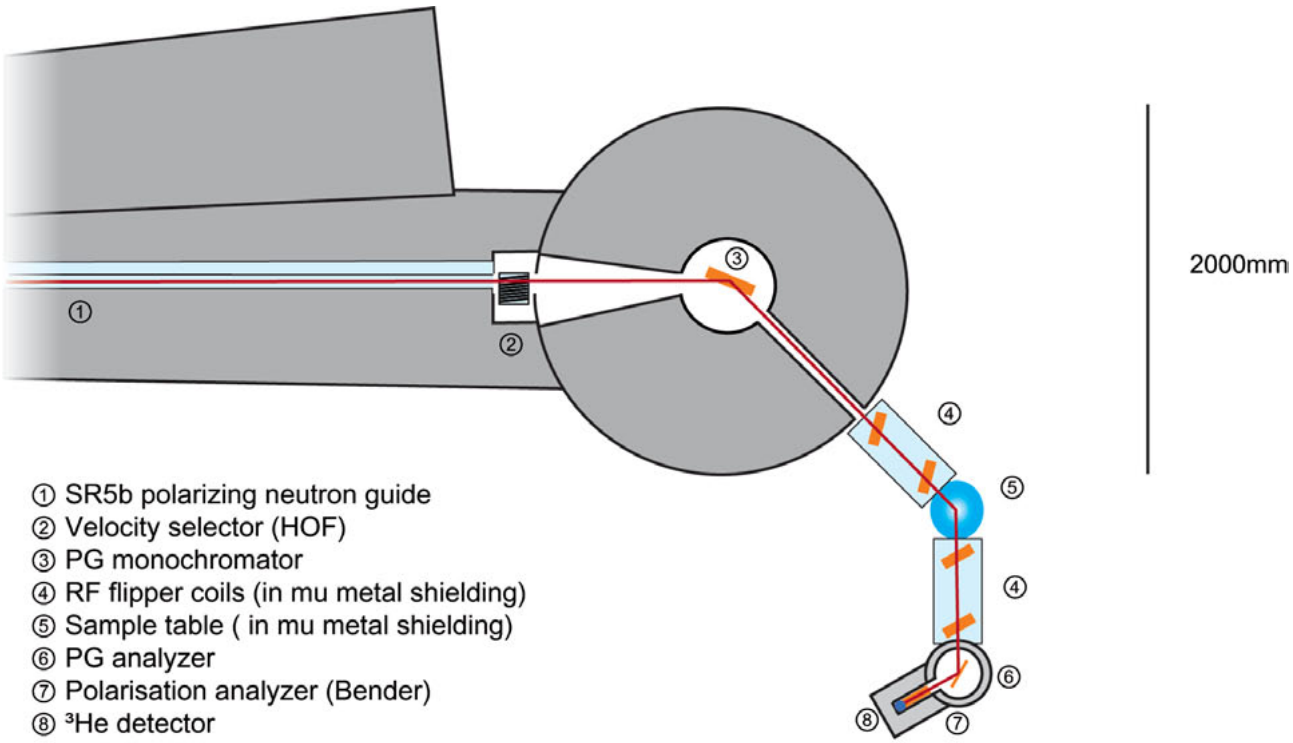


Figure 3: Intrinsic magnon linewidth Γ in antiferromagnetic MnF_2 at temperatures ranging from 15 to 40 K, as a function of q. We have plotted [Γ (T, q) - Γ (3 K, q)], where Γ (3 K, q) is given in the inset. (S. Bayrakci et al., Science 312, 1927 (2006))



Sample Environment

Besides the standard FRM II sample environment a dedicated dilution cryostat with a base temperature of 6 mK is available.

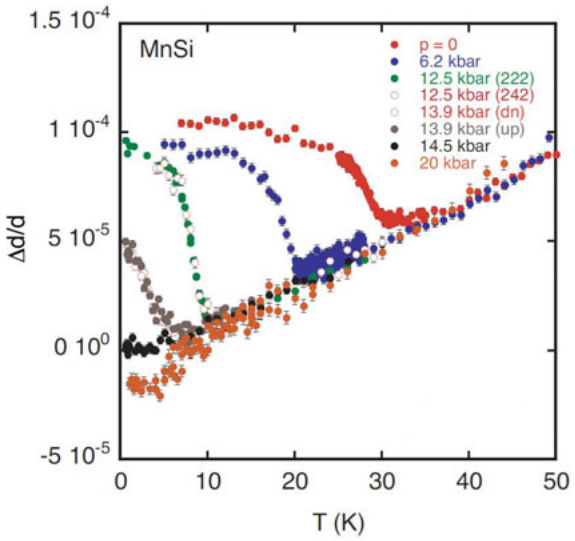


Figure 4: Temperature dependence of magnetic and electronic contributions, a2, of the lattice constant of MnSi at various pressures measured by Larmor-diffraction. The inset displays changes of the lattice constant at ambient pressure versus T_2 as normalized to a_0 = 4.58Å. The relative resolution is $\Delta d/d=1.5x10^{-6}$ (C. Pfleiderer et al, Science 316, 1510, (2008)).

Technical Data

Primary beam

- thermal beam tube SR5
  polarizing supermirror bender
  1.3 $Å^{-1} < k_i < 7.0 Å^{-1}$
- Velocity selector
  Astrium type, as higher order wavelengths filter

Monochromator

- PG (002) or (004)
  variable focussing horizontal and vertical

Analyzer

- PG (002)
  variable horizontal focussing
- Heusler (111) (polarized neutrons)
  variable horizontal focussing

Spin echo

- Resonance spin echo, enclosed by mu-metal magnetic screen.

Dr. Thomas Keller

Phone: +49.(0)89.289.12164
Email: thomas.keller@fkf.mpg.de

Phone Instrument: .14816

Prof. Dr. Bernhard Keimer

Phone: +49.(0)711.689.1650
Email: b.keimer@fkf.mpg.de

www.frm2.tum.de/trisp

TOFTOF

cold neutron time-of-flight spectrometer

3 meV. The monochromatic neutron pulses are focussed to the sample by a converging super-mirror ($2 \leq m \leq 3.6$) neutron guide. The scattered neutrons are detected by 1000 ^{3}He counting tubes mounted around the sample at a distance of 4 m. The time-of-flight for any detected neutron is measured by the detector electronics with an accuracy of up to 50 ns.

Typical Applications

TOFTOF combines high resolution, high neutron flux, and perfect flexibility with an exceptional low background and a well shaped and symmetric resolution function.
It is perfectly suited for a variety of different topics like:

- proton diffusion in hydrogen storage materials
- atomic and molecular mobility in liquids
- polymer and protein dynamics
- molecular magnetism and the dynamics of other magnetic systems

Sample Environment

Among the FRM II standard sample environment the following devices are available at TOFTOF:

- CCR / CryoFurnace (4 K – 600 K)
- Circulation thermostat furnace (CTF 1) (255 K – 450 K)
- High temperature furnace (RT – 1800°C)

Description

TOFTOF is a direct geometry multi-chopper time-of-flight spectrometer operated with incident neutrons from the undermoderated cold source of the reactor.
The 60 m long s-shaped curved primary neutron guide acts as a wavelength filter for the incident neutrons with a cutting edge for neutrons at λ_i =1.38 Å leading to a continuously high neutron flux over a wide wavelength range. Within the primary spectrometer the incident continuous neutron flux is pulsed and subsequently monochromatized using a system of seven high speed rotating chopper discs. Selecting an adequate incident wavelength and adjusting the chopper rotational frequency the resolution can be adapted to the needs of the experiment between 2 µeV and

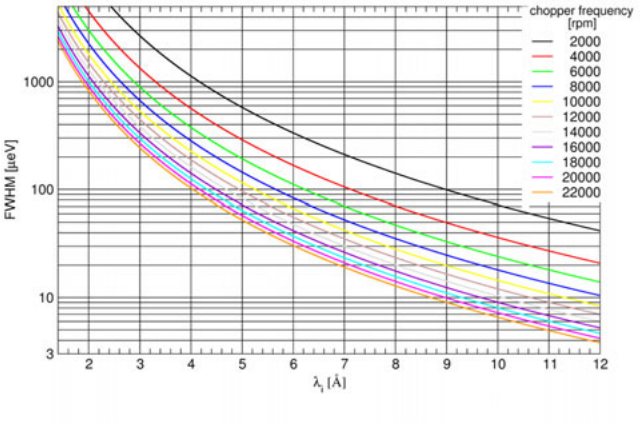
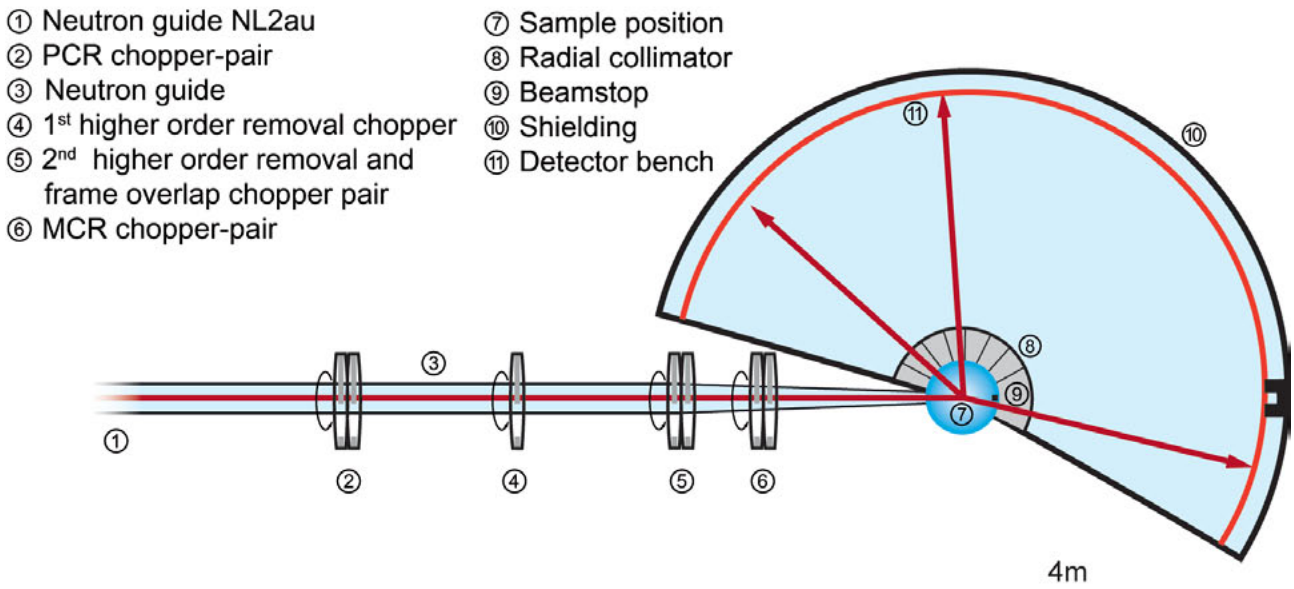


Figure 1: Elastic resolution as a function of the incident neutron wavelength for selected chopper rotational frequencies



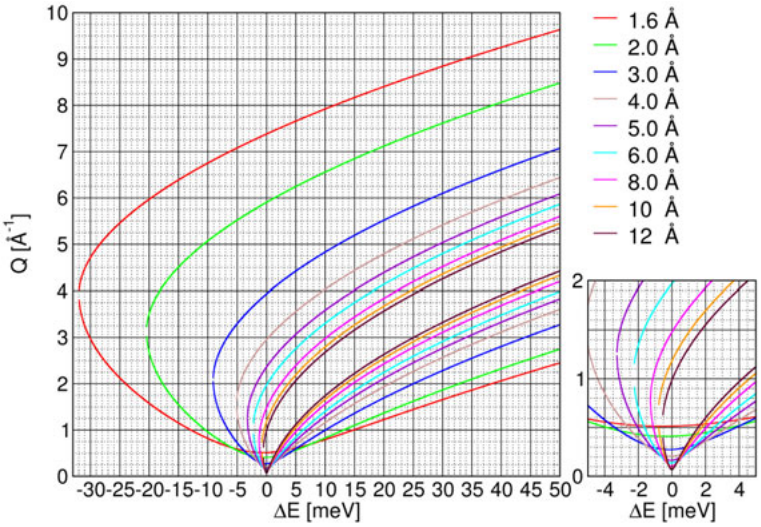


Figure 2: Dynamic range of the TOFTOF spectrometer for different incident wavelengths

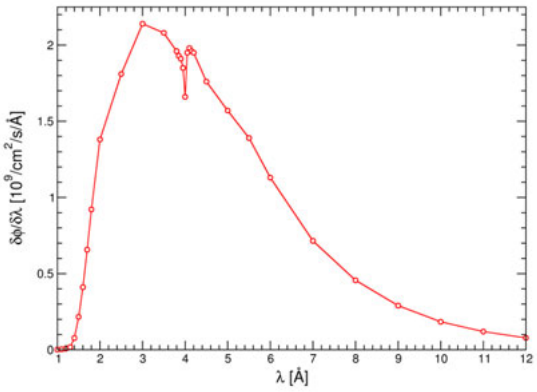


Figure 3: Incident differential white neutron flux at the sample position as measured by a calibrated beam monitor

Technical Data

Primary Beam	
• Neutron guide	NL2au
• Number of chopper discs	7
• Chopper frequency range	400 min^{-1} – 22000 min^{-1}
• Diameter of chopper disc	600 mm
• Cross section of neutron guide at the entrance	44 × 100 mm^2
• Cross section of neutron guide 20 cm in front of sample position	23 × 47 mm^2
Main Parameters	
• Adjustable range of incident neutrons	1.4 – 16 Å
• Elastic energy resolution	2 µeV – 3 meV
• Range of energy transfers	-30 meV – 50 meV
• Integral neutron flux of the white beam at sample position	10^{10} n/cm^2s
• Angular range of the detector bank	-15° to -7° and 7° to 140°

Dr. Tobias Unruh

Phone: +49.(0)89.289.14735
Email: tobias.unruh@frm2.tum.de

Phone Instrument: .14881

Dr. Giovanna Giulia Simeoni

Phone: +49.(0)89.289.14975
Email: giovanna.simeoni@frm2.tum.de

www.frm2.tum.de/toftof

SPHERES

backscattering spectrometer

Description

SPHERES (SPectrometer for High Energy RESolution) is a third-generation backscattering instrument with focussing optics and a phase-space-transform chopper. It is a versatile spectrometer for investigating atomic and molecular dynamics on a GHz scale.

The necessary filtering of neutron energies is achieved by Bragg reflection from perfect monochromator and analyzer crystals under angles close to 180°. The backscattering geometry makes it unavoidable to use a primary beam deflector and a duty-cycle chopper. In SPHERES, these two functions are realized jointly by a chopper that bears deflector crystals on its circumference. This leads to a particularly compact spectrometer layout so that full use can be made of the focussing neutron guide. As an additional advantage, the fast motion of the deflector crystals achieves a phase-space transform of the primary spectrum, thereby enhancing the flux at the sample.

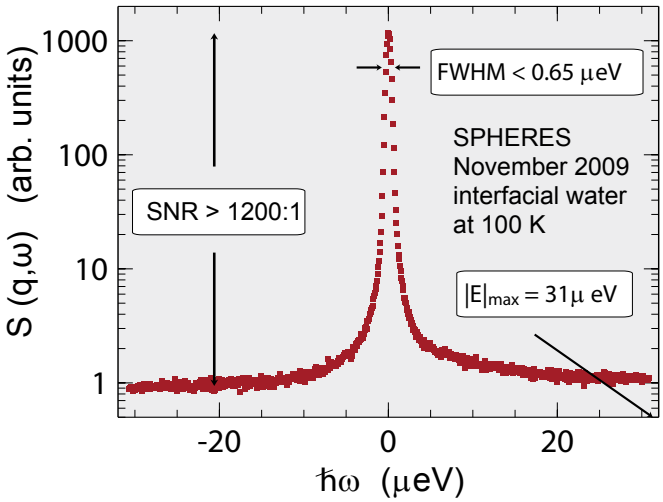


Figure 1: A resolution of 0.65 ueV, a dynamic range of ±31 μeV, and a signal-to-noise ratio of 1000 : 1 or better are routinely achieved in user experiments.

The principal figures of merit (spectral flux, resolution, dynamic range, signal-to-noise ratio - Fig. 1) qualify SPHERES as worldwide leading. In the near future, count rates and signal-to-noise ratio will be further improved by filling the entire instrument with argon, thereby avoiding air scattering in the secondary spectrometer. Another gain in flux will be achieved by a more efficient phase-space transform chopper, which is currently under development.

As a multi-detector instrument with relaxed angular resolution, SPHERES is particularly suited for studying tagged-particle motion by incoherent scattering. A hot topic is the dynamics of water in confined geometry. The unprecedented sensitivity of SPHERES helps us to detect the onset of quasi-elastic scattering deep in the supercooled state [1]. Other important applications are hyperfine splitting in magnetic materials [2] and rotational tunneling [3]. The high count rates allow inelastic temperature scans (Fig. 2) and real-time kinetic experiments.

Raw histograms are accumulated on an equidistant ω grid. A script driven program, SLAW [4], is provided to normalize the raw counts, to perform optional binning, and to deliver S(q,ω) in a variety of output formats so that users are not bound to any specific data analysis programm.

In data fitting, it is critcially important to convolute theoretical models with the measured resolution function in an efficient and numerically stable way. We strive to support best practice through our FRIDA package [5].

[1] W. Doster, S. Busch, A. M. Gaspar, M.-S. Appavou, J. Wuttke, H. Scheer, Phys. Rev. Lett. 104, 098101 (2010).

[2] T. Chatterji, G. J. Schneider, and R. M. Galera, Phys. Rev. B 78, 012411 (2008).

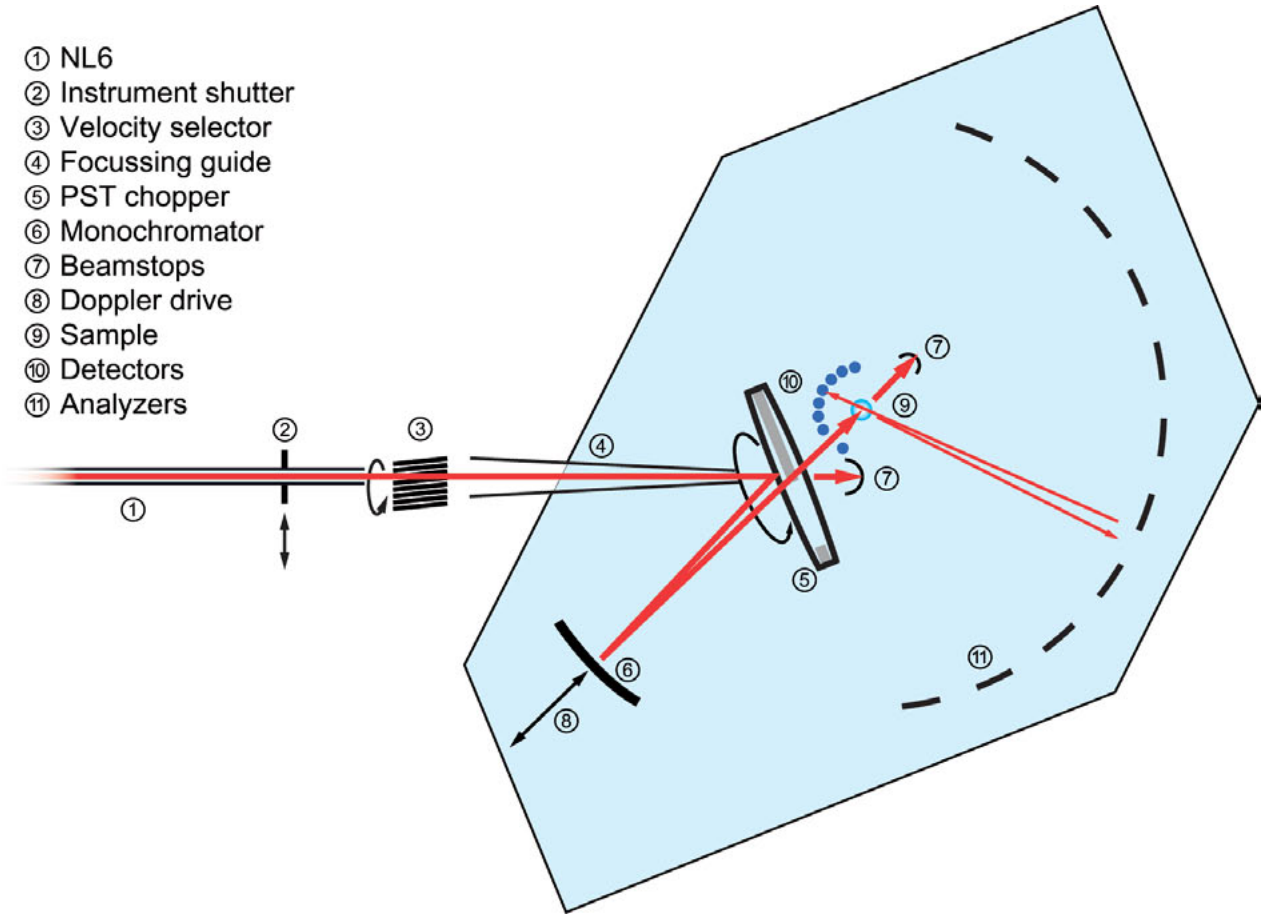
[3] M. Prager, A. Pawlukojc, A. Wischnewski, J. Wuttke, J. Chem. Phys. 127, 214509 (2007).

[4] J. Wuttke: SLAW - a neutron histogram to scattering law converter, http://www.messen-und-deuten.de/slaw.

[5] J. Wuttke: FRIDA - fast reliable interactive data analysis, http://www.messen-und-deuten.de/frida.

Jülich Centre for Neutron Science

Bundesministerium für Bildung und Forschung



Typical Applications

- Hyperfine splitting
- Molecular reorientations and rotational tunneling
- Dynamic signature of phase transitions
- Hydrogen diffusion
- Liquid dynamics
- Polymer relaxation
- Protein aggregation

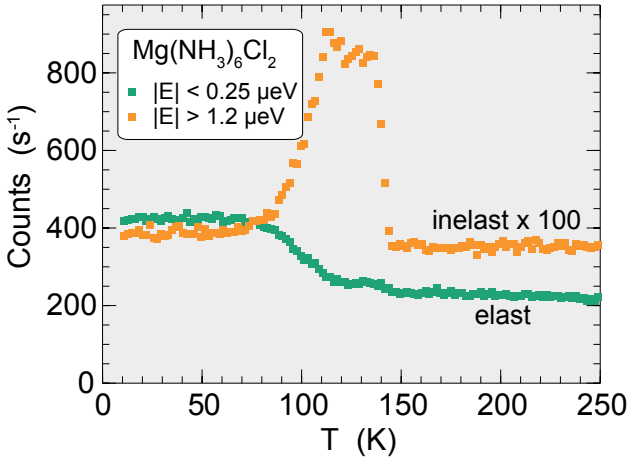


Figure 2: This inelastic temperature scan, measured during 23 h, revealed a hitherto unknown phase transition in $Mg(NH_3)_6Cl_2$.

Sample Environment

- Cryofurnace 2..700 K
- Dilution inset 20 mK
- Furnace

Technical Data

Primary beam	
• Neutron guide	NL6-S
• Neutron wavelength	6.27 Å
• Neutron energy	2.08 meV

Main parameters	
• Resolution FWHM	0.60 – 0.65 μeV
• Dynamic range	± 31 μeV
• Q range	0.2 – 1.8 $Å^{-1}$
• Signal to noise	>1000 : 1
• Flux after selector	10^{10} s^{-1}
• Flux at sample	$8 \cdot 10^5$ s^{-1}
• Illuminated area	30 × 30 mm^2

Dr. Joachim Wuttke

Phone: +49.(0)89.289.10715
Email: j.wuttke@fz-juelich.de

Phone Instrument: .14875

Dr. Gerald J. Schneider

Phone: +49.(0)89.289.10718
Email: g.j.schneider@fz-juelich.de

www.jcns.info/jcns_spheres

RESEDA

resonance spin echo spectrometer

Description

RESEDA is a high resolution spin echo spectrometer installed at the cold neutron guide NL 5 in the neutron guide hall of the FRM II. The wavelength is adjustable from 3.5 Å to 12 Å by a velocity selector. RESEDA provides a large time and scattering vector range for quasi-elastic measurements.
In quasi-elastic measurements, the energy transfers due to inelastic scattering are small compared to the initial neutron energy. The final polarization value of the neutron spin echo renders the (normalized) intermediate scattering function S(q,τ) being the Fourier transform of the scattering function S(q,ω). The analysis of S(q,τ) provides characteristic parameters, e.g. relaxation time and amplitude of the dynamic processes in the sample investigated. The determination of S(q,τ) is feasible for different q-values and/or different temperatures. RESEDA allows the measurement of two different q-values simultaneously due to two secondary spectrometer arms, which operate independently.
RESEDA supports both Neutron Spin Echo (NSE) and Neutron Resonance Spin Echo (NRSE). In both techniques, the velocity (or energy) change of neutrons due to inelastic scattering processes is obtained very sensitively by measuring the spin phase. It results from the spin precession within two magnetic fields located before and after the sample. NSE and NRSE differ in the way the magnetic fields are produced. In NSE, the magnetic fields are produced by long solenoids, whereas in NRSE, two compact RF spin flip coils combined with a zero field environment replace the solenoids.

In order to prevent the neutron spin from uncontrolled precessions, the neutron flight path is surrounded by a double µ-metal shielding, which minimizes magnetic stray fields in the spectrometer arms and at the sample position. Besides being a prerequisite for NRSE, the zero field environment provides the possibility to perform spherical polarization analysis.

Typical Applications

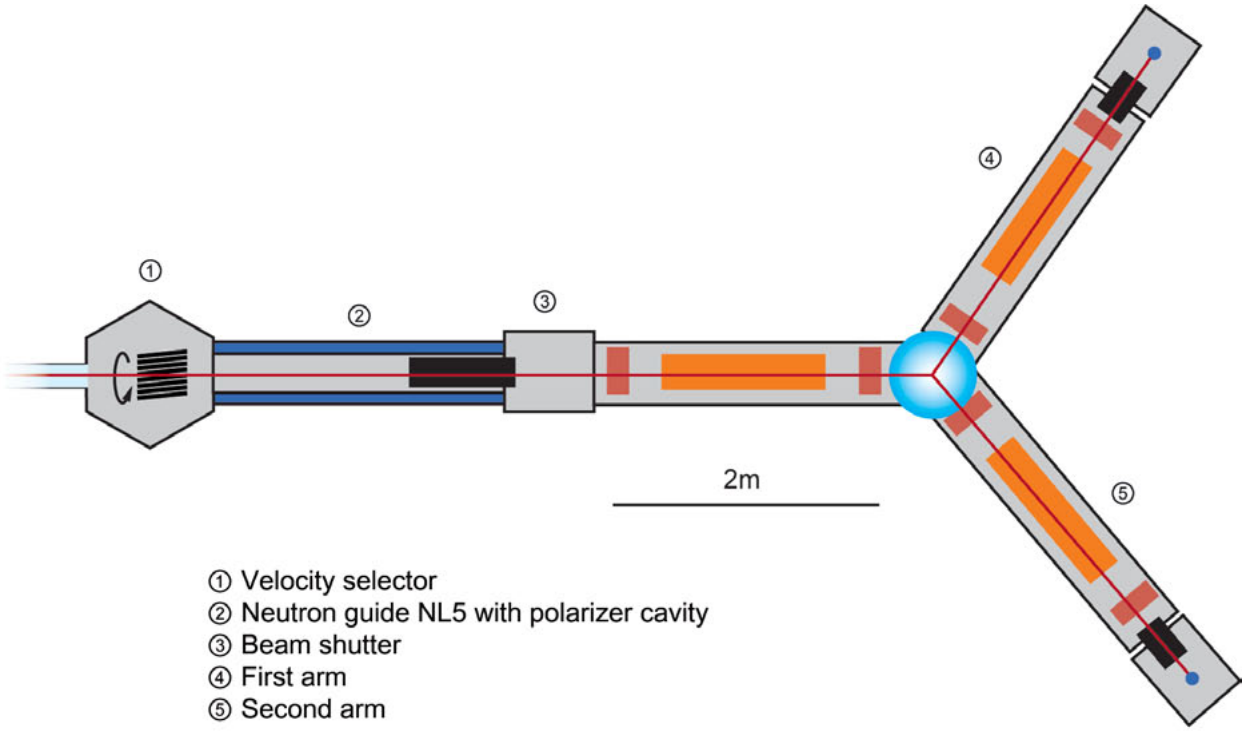
RESEDA is ideally suited for dynamical studies in macromolecular and magnetic systems, as for example:

- Diffusion of polymers in bulk or confinement
- Polymer melts
- (Spin-) Glass dynamics
- Soft biological systems
- Magnetic fluctuations
- Dynamics of water in porous media
- Diffusion processes in ionic liquids

Besides that, RESEDA is employed intensively for studying magnetic dynamics in materials with ferromagnetic correlations. For example, manganese silicide (MnSi) is a 3d intermetallic compound that crystallizes in a cubic structure and exhibits a single-handed helical magnetic order with a period of approximately 180 Å due to the interplay between ferromagnetic exchange and the Dzyaloshinskii-Moriya interaction. In the vicinity of the critical temperature T_c = 28.85 K, the time scale of the magnetic fluctuations matches well the spin-echo times available at RESEDA. Above T_c, long-range magnetic order is lost. However, chiral fluctuations still persist. The high flux of RESEDA at the wavelength of 5.5 Å allows a clear identification of the magnetic fluctuations. Appropriate collimation of the neutron beam in front of the sample position enables measurements down to small Q-values. The results of typical NSE-NRSE scans on MnSi, corrected for instrumental resolution, are shown in figure 1. Around the ordering vector at Q = 0.039 $Å^{-1}$, the fluctuations are very slowly decaying within about 1.5 ns. With increasing Q, the relaxation rate of the fluctuations increases quickly.

Sample Environment

The standard closed-cycle cryostats available at the FRM II fit within the double µ-metal shielding at the sample position. One cryostat equipped with sample stick (CCR) enables simple sample change. The CC cryostat can be supplied with a vacuum



tight chamber surrounding the sample making measurements in a wide temperature range possible with any buffering gas around the sample.
This vacuum tight chamber is used, for example, in experiments with samples of well defined water-content or hydration level. Thanks to its compactness, the CC cryostat can be tilted in any directions within the double μ-metal shielding up to angles of ± 4.5°. Moreover, it can be equipped with a ^{3}He or dilution insert thus extending the available temperatures to the mK regime

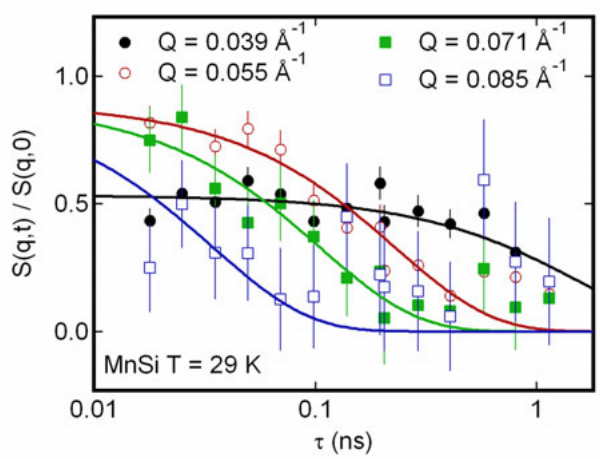


Figure 1: Typical NSE-NRSE scans on MnSi

Technical Data

Primary beam

- Neutron guide NL5-S
  Length 65 m
  Cross section 29 × 30 mm²
- Wavelength selection by velocity selector
  28000 rpm max. speed
  λ 3.5 – 12 Å
- Cavity type mirror polarizer
  2 m length
  Coating m = 3

Spectrometer

- 2.6 m arm length
- μ-metal magnetic shielding (doubled)
- two secondary spectrometer arms
- Bender type polarization analyzer
- ^{3}He detectors

Characteristic parameters

- Flux (at sample position, λ= 4.5 Å):
  $\Phi \geq 10^7$ n/cm²s
- Maximum magnetic field strength B = 300 G
- Spin echo time range t = 0.001 – 5 ns
- Energy resolution 0.1 – 600 μeV
- Maximum scattering angle 2θ = 93°
- Maximum scattering vector Q = 2.5 Å^{-1} (λ = 4.5 Å)

Dr. Wolfgang Häußler

Phone: +49.(0)89.289.14921
Email: wolfgang.haeussler@frm2.tum.de

Phone Instrument: .14874

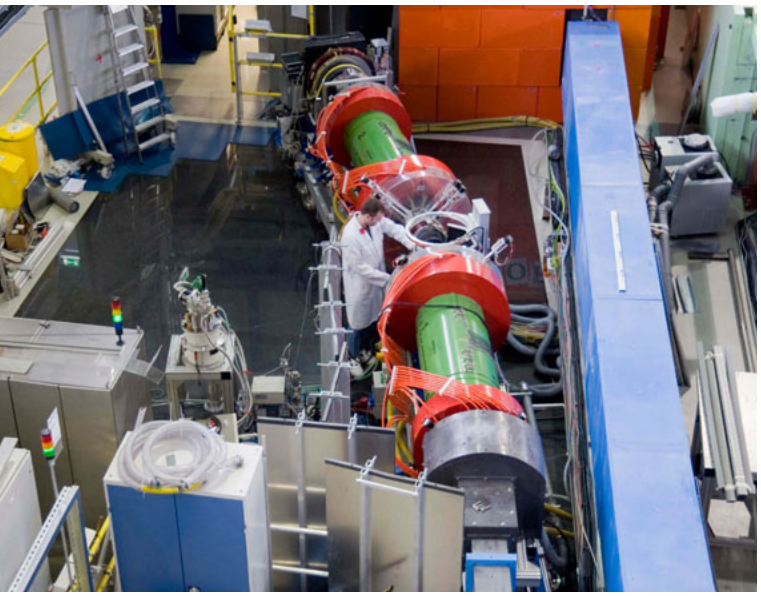
Dr. Julia Repper

Phone: +49.(0)89.289.14668
Email: julia.repper@frm2.tum.de

www.frm2.tum.de/reseda

J-NSE

neutron spin-echo spectrometer



Description

The neutron spin echo technique uses the neutron spin as an indicator of the individual velocity change the neutron suffered when scattered by the sample. Due to this trick the instrument accepts a broad wavelength band and at the same time is sensitive to velocity changes down to $10^{(-5)}$. However the information carried by the spins can only be retrieved as the modulo of any integer number of spin precessions as intensity modulation proportional to the cosine of a precession angle difference. The measured signal is the cosine transform S(Q, τ) of the scattering function S(Q, ω). All spin manipulations only serve to establish this special type of velocity analysis. For details see “Neutron Spin Echo”, ed. F. Mezei, Lecture Notes in Physics, Vol. 128, Springer Verlag, Heidelberg, 1980.

Due to the intrinsic Fourier transform property of the NSE instrument it is especially suited for the investigation of relaxation-type motions that contribute at least several percent to the entire scattering intensity at the momentum transfer of interest. In those cases the Fourier transform property yields the desired relaxation function directly without numerical transformation and tedious resolution deconvolution. The resolution of the NSE may be corrected by a simple division.

For a given wavelength the Fourier time range is limited to short times (about 2 ps for the FRM II-setup) by spin depolarization due to vanishing guide field and to long times by the maximum achievable field integral J. The time is proportional to $J \times \lambda^3$. The J-NSE may achieve a J = 0.5 Tm corresponding to τ= 48 ns at λ = 8 Å.

The instrument itself consists mainly of two large water-cooled copper solenoids that generate the precession field. The precession tracks are limited by the π/2-flippers and the π-flipper near the sample position. The embedding fields for the flippers are generated by Helmholtz-type coil pairs around the flipper locations. After leaving the last flipper the neutrons enter an analyzer containing 60 (30 × 30 cm^2) CoTi supermirrors located in a solenoid set. These mirrors reflect only neutrons of one spin direction into the multidetector. By the addition of compensating loops the main coils and the analyzer coil are designed such that the mutual influence of the different spectrometer components is minimized.

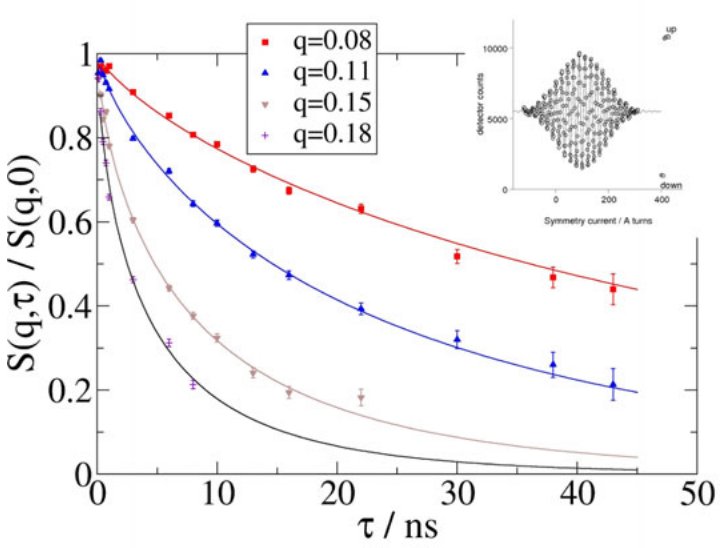
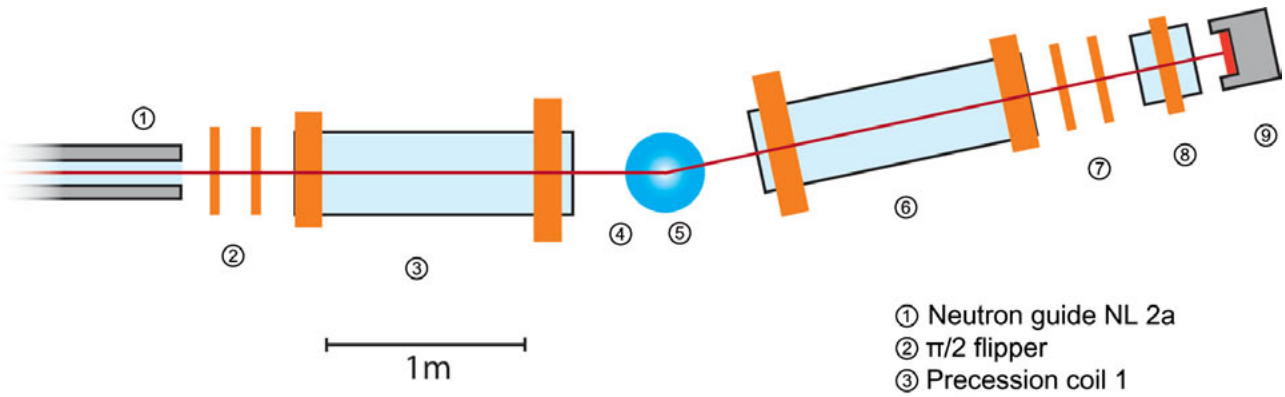


Figure 1: S(q, τ) of a bicontinuous microemulsion at different q values. The inset shows a spin echo group, the amplitude as a measure of the polarization left contains the desired information



① Neutron guide NL 2a
② π/2 flipper
③ Precession coil 1
④ π flipper
⑤ Sample space
⑥ Precession coil 2
⑦ π/2 flipper
⑧ Analyzer
⑨ Detector

Typical Applications

The spin echo spectrometer NSE is especially suited for the investigation of slow (~ 1-100 ns) relaxation processes. Typical problems from the fields of "soft matter" and glass transition are:

- Thermal fluctuations of surfactant membranes in microemulsions
- Polymer chain dynamics in melts
- Thermally activated domain motion in proteins, which is an important key for understanding the protein function.

Example Experiment

The intermediate scattering function S(q,τ) of a bicontinuous microemulsion is shown in figure 1, where one probes the thermal fluctuations of the surfactant membrane at different q values. The inset shows an echo group obtained in the direct beam at λ = 5 Å and a Fourier time of τ = 0.24 ns. The maximum amplitude of the oscillation compared to the average contains the desired information on the time dependence of S(Q, τ). The residual intensity at the minimum is caused by the imperfection of the polarizes, general background and - rather for higher τ's - by magnetic path integral in homogeneities.

Technical Data

Main parameters

- Polarized neutron flux at sample position
  7 Å: $1 \cdot 10^7$ n/cm²s
  12 Å: $6.8 \cdot 10^5$ n/cm²s
- Momentum transfer range:
  0.02 – 1.5 $Å^{-1}$
- Fourier time range:
  2 ps (4.5 Å) < τ < 350 ns (16 Å)
- Max. field integral: 0.5 Tm

Primary beam

- Neutron guide NL2a
- Polarisation:
  Short wavelength by bent section with FeSi M = 3 remanent supermirror coating
  Long wavelength by FeSi polariser at entrance of the spectrometer
- Cross section of guide: 6 cm × 6 cm
- max. sample size: 3 cm × 3 cm
- Collimation:
  By source and sample size or wire collimators 0.5° × 0.5°

Analyzer

30 cm × 30 cm CoTi supermirror ventian blind

Detector

32 × 32 1 cm² cells ^{3}He multidetector

Dr. Olaf Holderer

Phone: +49.(0)89.289.10707
Email: o.holderer@fz-juelich.de

Phone Instrument: .14903

Dr. Michaela Zamponi

Phone: +49.(0)89.289.10793
Email: m.zamponi@fz-juelich.de

www.frm2.tum.de/jnse

DNS

Diffuse scattering neutron time of flight spectrometer

Description

DNS is a versatile diffuse scattering cold neutron time-of-flight spectrometer with polarization analysis. It allows the unambiguous separation of nuclear coherent, spin incoherent and magnetic scattering contributions simultaneously over a large range of scattering vector Q and energy transfer E. With its compact size DNS is optimized as a high intensity instrument with medium Q- and E- resolution.
New chopper and position sensitive detector systems are to be installed at DNS. This is expected to largely improve possibilities for single-crystal time-of-flight spectroscopy with efficient measurements in all 4 dimensions of S(Q,E). With its unique combination of single-crystal time-of-flight spectroscopy and polarization analysis, DNS is also complimentary to many modern polarized cold neutron triple-axis spectrometers.

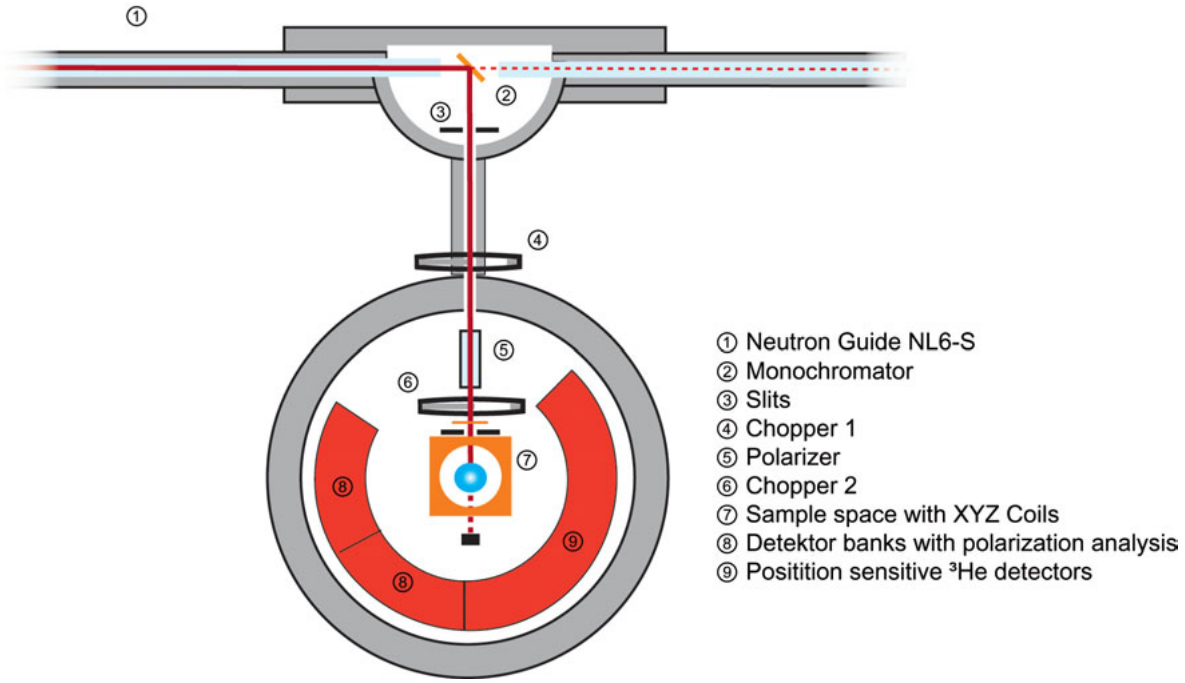
Typical Applications

With the increased flux and efficiency at FRM II, DNS becomes ideal for the studies of complex spin correlations, such as in highly frustrated magnets and strongly correlated electrons, as well of the structures of soft condensed matter systems, such as the nanoscale confined polymers and proteins, via polarization analysis. The exploration of unusual magnetic properties can also be efficiently undertaken on single-crystal samples by reciprocal space mapping. In addition to the separation of magnetic cross section from nuclear and spin-incoherent ones, polarization analysis also allows to distinguish in detail the anisotropy of spin correlations. It has also been well demonstrated that polarized powder diffraction on DNS is complementary to standard neutron powder diffraction and may be extremely useful for magnetic structure refinements, particularly in case of small moments by improving the signal to background ratio. DNS also represents a powerful instrument for the soft condensed matter community for the separation of nuclear coherent scattering from often dominating spin incoherent scattering background. The main applications can be summarized as the follows,

- Application of polarization analysis: uniaxial-, longitudinal- and vector-PA
- Magnetic, lattice and polaronic correlations: geometrically frustrated magnets, strongly correlated electrons, emergent materials
- Single-crystal and powder time-of-flight spectroscopy: single-particle excitations, magnons and phonons
- Soft condensed matters: separation of coherent scattering from hydrogenous materials, polymer, liquids and glasses

Sample Environment

- Top-loading CCR
- Closed-cycle cold head
- Orange-type cryostat
- Cryo-furnace
- Dilution ^{3}He/^{4}He cryostat insert (~20mK)
- Cryomagnet (self-shielding, vertical field up to 5T)



Technical Data

Monochromator

- Neutron guide NL6-S
- Horizontal- and vertically adjustable double-focusing
- PG (002), d = 3.355 Å
- Crystal dimensions: 2.5 × 2.5 cm^2 (5 × 7 crystals)
- Wavelengths range: 2.4 Å < λ < 6 Å

Double chopper system

- Chopper frequency ≤ 300 Hz
- Repetition rate ≤ 900 Hz
- Chopper disks: Titanium, 3 slits, Ø = 420 mm

Flux at sample

- Non-polarized ~ 10^8 n/cm^2s
- Polarized ~ $5 \cdot 10^6 – 10^7$ n/cm^2s (polarizer: m = 3 supermirror benders)

Detector banks for non-polarized neutrons

- 128 position sensitive ^{3}He tubes Ø = 1.27 cm, height ~100 cm
- Total solid angle covered: 1.9 sr
- Covered scattering angles in the horizontal plane: $0° < 2\theta \leq 135°$

Detector banks for polarized neutrons

- 24 detection units: Polarization analysis by m = 3 supermirror benders ^{3}He detector tubes, Ø = 2.54 cm, height 15 cm
- Covered scattering angle in the horizontal plane: $0° < 2\theta \leq 150°$
- Q_{max}
  λ_i = 2.4 Å (E_i = 14.2 meV): 4.84 $Å^{-1}$
  λ_i = 6 Å (E_i = 2.28 meV) 1.93 $Å^{-1}$

Energy resolution

λ_i = 2.4 Å (E_i = 14.2 meV): 1 meV
λ_i = 6 Å (E_i = 2.28 meV): 0.1 meV

Dr. Yixi Su

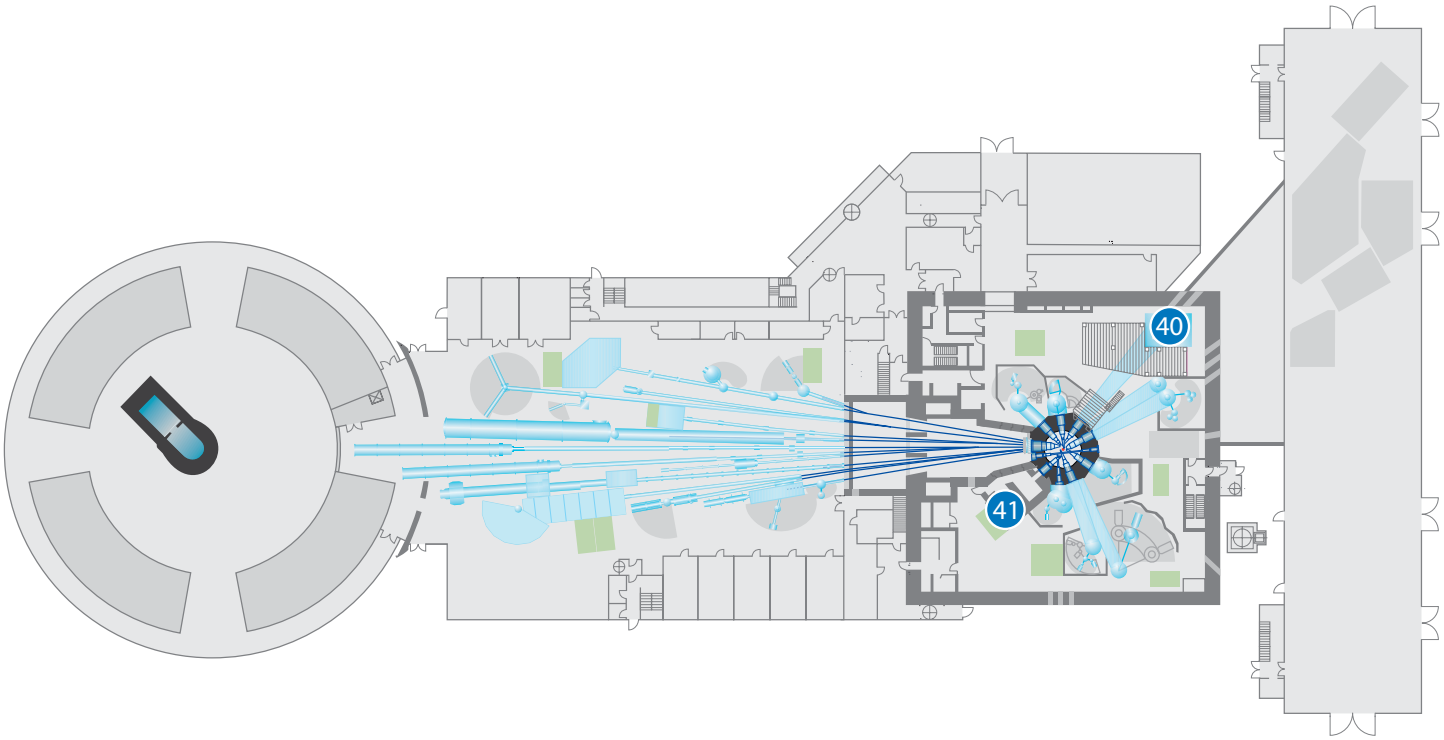
Phone: +49.(0)89.289.10714
Email: y.su@fz-juelich.de

Phone Instrument: .14876

Dr. Wouter Borghols

Phone: +49.(0)89. 289.10716
Email: w.borghols@fz-juelich.de

www.jcns.info/jcns_dns



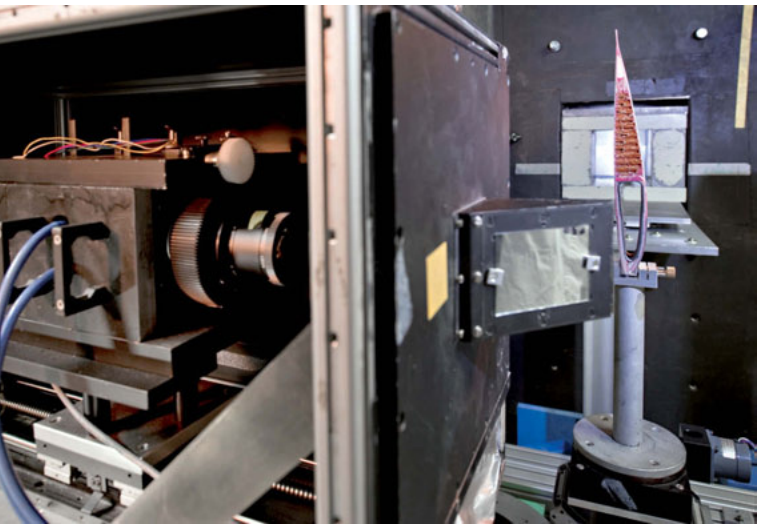
ANTARES
cold neutron radiography and tomography station
p. 66 / 67

NECTAR
radiography and tomography using fission neutrons
p. 68 / 69

Imaging

ANTARES

cold neutron radiography and tomography station



Description

The neutron imaging facility ANTARES is located at the cold neutron beam port SR4b of the FRM II. Based on a pinhole camera principle with a variable collimator located close to the beam port, the facility provides the possibility for a flexible use in high resolution and high flux imaging. ANTARES offers two different detector positions in chamber 2 and 3, which may be chosen according to the requirements for beam size, neutron flux and spatial resolution.
Chamber 1 is separately accessible for the optional installation of beam and spectrum shaping devices provided by the user. At this position ANTARES also offers built-in options such as a double crystal monochromator, interference gratings, coded apertures, and a Be-filter which are readily available for standard user operation. Furthermore, a 320 kV X-ray tube can be used for imaging in the same beam geometry as with neutrons, allowing for easy image registration and profiting of the advantages of both complementary techniques.

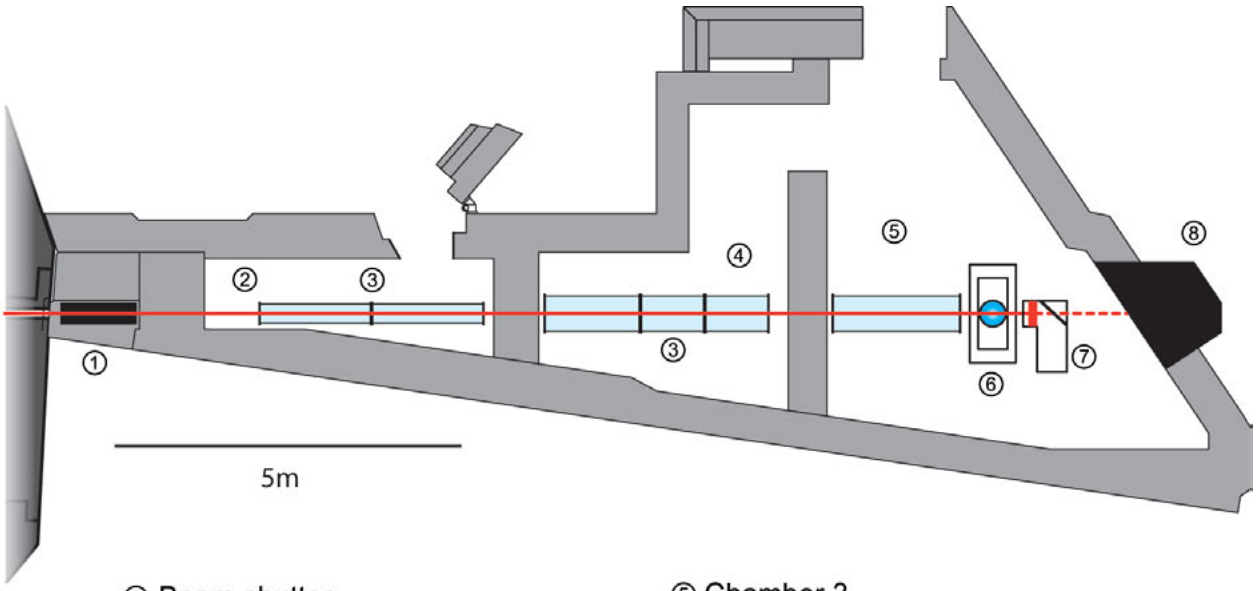
Typical Applications

The ANTARES Neutron Imaging facility is designed to deliver radiographs and computed tomography of samples, similar to an X-ray machine. The achieved information is often complementary to X-ray measurements, with its most important features the high penetration of metals (Fe ~ 4 – 5 cm, Al ~20 – 30 cm, Pb ~10 – 20 cm) and the high sensitivity for hydrogen. These allow to visualize metal machine parts as well as liquids, sealants and plastics inside of metal parts. Liquid contrast agents can be employed for crack and void detection.

Examples of different techniques and their typical applications:

- **Standard neutron radiography**: Moisture in sandstone, o-rings in machine parts, aerospace pyrotechnical components
- **Computed tomography**: Geological samples, mineral phases, voids in carbon fiber structures (with contrast agents), machine parts, biological samples as lung tissue
- **Continuous radioscopy**: Video speed radiography of dynamic processes like boiling in refrigerators or water boilers
- **Stroboscopic imaging**: Identical time windows of cyclic processes integrated on a camera, then shift of time window: Oil distribution in running engines
- **Phase contrast**: Edge enhancement, aluminium foams, interface of similar alloys
- **Energy / wavelength scan**: Scanning for Bragg edges, phase or material identification, examination of welds.
- **Magnetic imaging**: Visualization of magnetic fields, fundamental research on ferromagnetic materials
- **Dark field imaging or small-angle scatter measurement**: Scatter grids used to suppress the direct beam, measuring the spatially resolved small angle scattering signal of steel samples
- **X-ray radiography**: Insertable 300 kV 9 mA X-ray tube, in identical beam geometry for overlay without registration

Figure 1: Radiography of a motorcycle engine.



① Beam shutter
② Chamber 1
③ Flight tubes
④ Chamber 2
⑤ Chamber 3
⑥ Sample Space
⑦ Detector
⑧ Beam Stop

Sample Environment

FRM II standard sample environment usable with ANTARES

- Closed-cycle cryostat CC 3 K < T < 300 K
- Closed-cycle cryostat CCR 3 K< T < 100 K
  using ^{3}He insert 500 mK < T < 4 K
  using ^{3}He/^{4}He dilution insert 50 mK < T < 1 K
- Vacuum furnace 340 K < T < 2100 K
- Mirror furnace RT < T < 900 K

Technical Data

Collimation and flux at the sample position

- L/D = 200, 4 · 10^8 n/cm^{2}s
- L/D = 400, 1 · 10^8 n/cm^{2}s
- L/D = 800, 2.6 · 10^7 n/cm^{2}s
- L/D = 8000, 2.6 · 10^5 n/cm^{2}s
- Beam size up to 35 × 35 cm^2

Neutron beam optics (optional)

- Double Crystal Monochromator:
  2.7 Å ≤ λ ≤ 6.5 Å (1 %<Δ λ / λ <3 %)
- Neutron Velocity Selector:
  2.5 Å ≤ λ≤ 8 Å (Δ λ / λ = 10 %)
- Beam Filters:
  Cd filter for epithermal imaging
  Be filter to suppress wavelengths λ < 4 Å
  Sapphire filter to suppress fast neutrons

Sample table

XY-Phi-table:
- Capacity: 500 kg
- Travel: x = 800 mm, y = 600 mm
- Rotation table: 360° rotation

Detection systems

- Camera box with mirror and scintillation screens of different sizes from 6 x 6 cm² to 40 x 40 cm², screen thickness from 10 µm to 200 µm, plus X-ray screens
- Standard detector: ANDOR cooled CCD camera, 2048 x 2048 pixels, 16 bit
- Intensified triggerable iStar ANDOR cooled CCD camera, 1024 x 1024 pixels, 16 bit
- Intensified NTSC video camera (30 fps) with analog frame grabber, MPEG-2 and DivX recording
- DürrDental Image Plate scanner for arbitrary imaging plates, focus size 12.5 – 100 µm
- Fuji BAS 2500 Image Plate scanner, focus size 25 – 100 µm
- X-ray and neutron imaging plates
- MAR345 image plate detector, 345 mm diameter, N-sensitive image plate

Dr. Burkhard Schillinger

Phone: +49.(0)89.289.12185
Email: burkhard.schillinger@frm2.tum.de

Phone Instrument: .14815

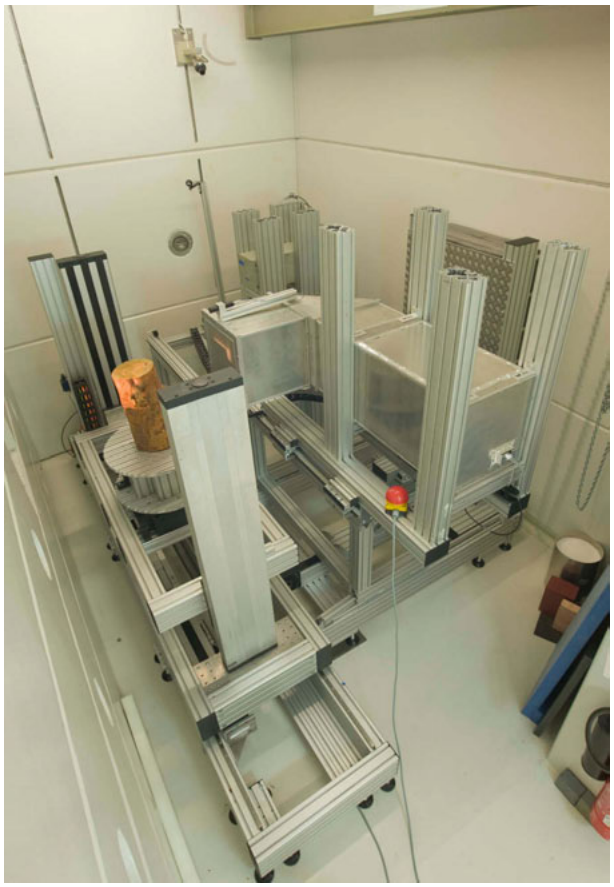
Dr. Michael Schulz

Phone: +49.(0)89.289.14718
Email: michael.schulz@frm2.tum.de

www.frm2.tum.de/antares

NECTAR

radiography and tomography using fission neutrons



Description

NECTAR is a versatile facility for the non-destructive inspection of various objects by means of fission neutron radiography and tomography, respectively. The resulting images often show complementary and / or additional information compared to conventional radiography and tomography using X-rays or gamma-radiation, especially in those cases, where large and / or dense objects have to be investigated, while still requiring sensitivity to hydrogen containing materials.

Examples are trunks, glued timbers, water or oil containing (metallic) objects (e. g. gear boxes), archaeological and art historical objects, turbine blades etc.

In addition to the investigation of static objects, time resolved radiography for slow processes is possible, like water intrusion in trunks. The time resolution is actually about 10 s, but will be further reduced in the near future.

As fission neutrons can easily penetrate dense materials, nearly all sample environments available at FRM II can be attached to the instrument.

The measured radiographs are available as tiff-files and can be processed by conventional image processing software. A pre-processing can take place at the facility using a set of routines specially developed for NECTAR being continuously extended.

Typical Applications

Figure 1 shows a selection of typical objects studied at the NECTAR instrument. In particular objects with high hydrogen content or massive items, where cold neutron radiography is not suitable.

Technical Data

Neutron source

Converter facility at FRM II
2 plates of uranium-silicide
(93 % ^{235}U, total 540 g), P = 80 kW

Neutron spectrum

Fission spectrum

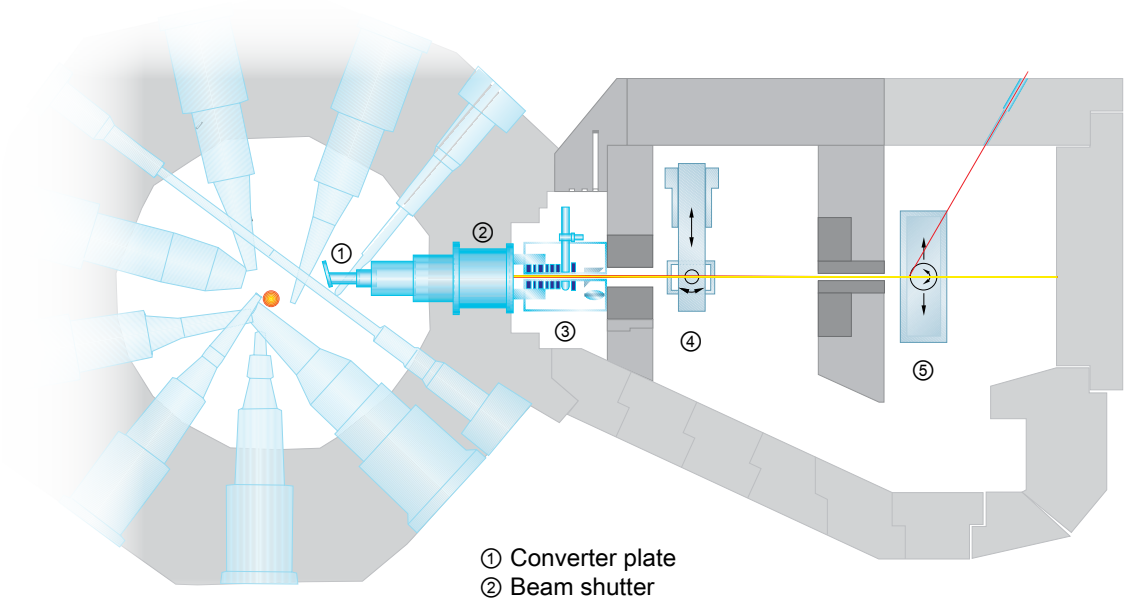
- Mean energy: 1.8 MeV
- Flux: 8.7 $\cdot 10^5$ $cm^{-2}s^{-1}$ – 4.7 $\cdot 10^7$ $cm^{-2}s^{-1}$ (depends on filter used)
- Best L/D: 233 ± 16 (with collimator, measured)

Sample space

Max. 80 cm × 80 cm × 80 cm
Max. 400 kg
Sample environments easily attachable
(e. g. pressure cells)

Detection systems

CCD-based (ANDOR DV434-BV, pco. 1600) detection systems with different converters, e. g. pp-converter with 30% ZnS and 30 cm x 30 cm x 0.24 cm) available



① Converter plate
② Beam shutter
③ Filters
④ Medical treatment station
⑤ Sample table NECTAR

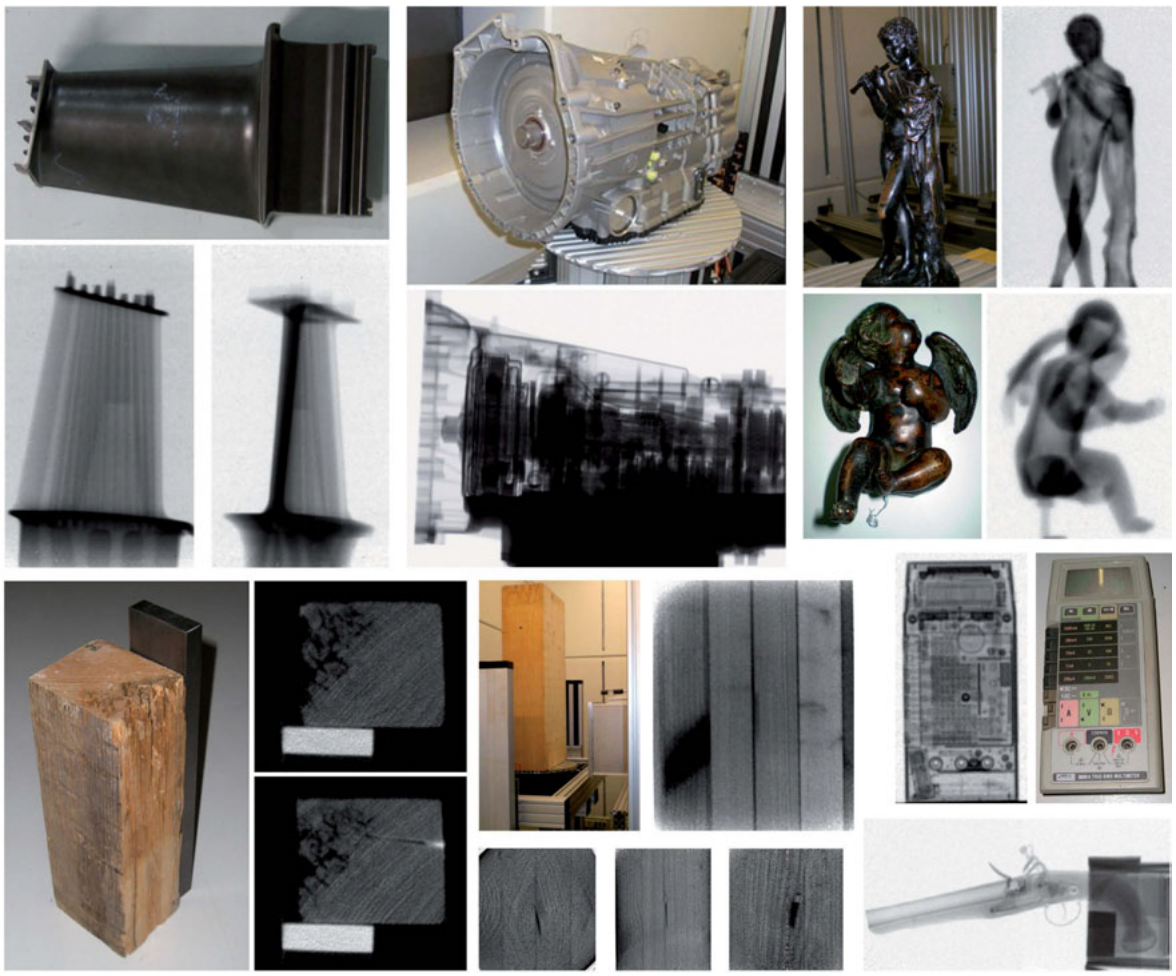


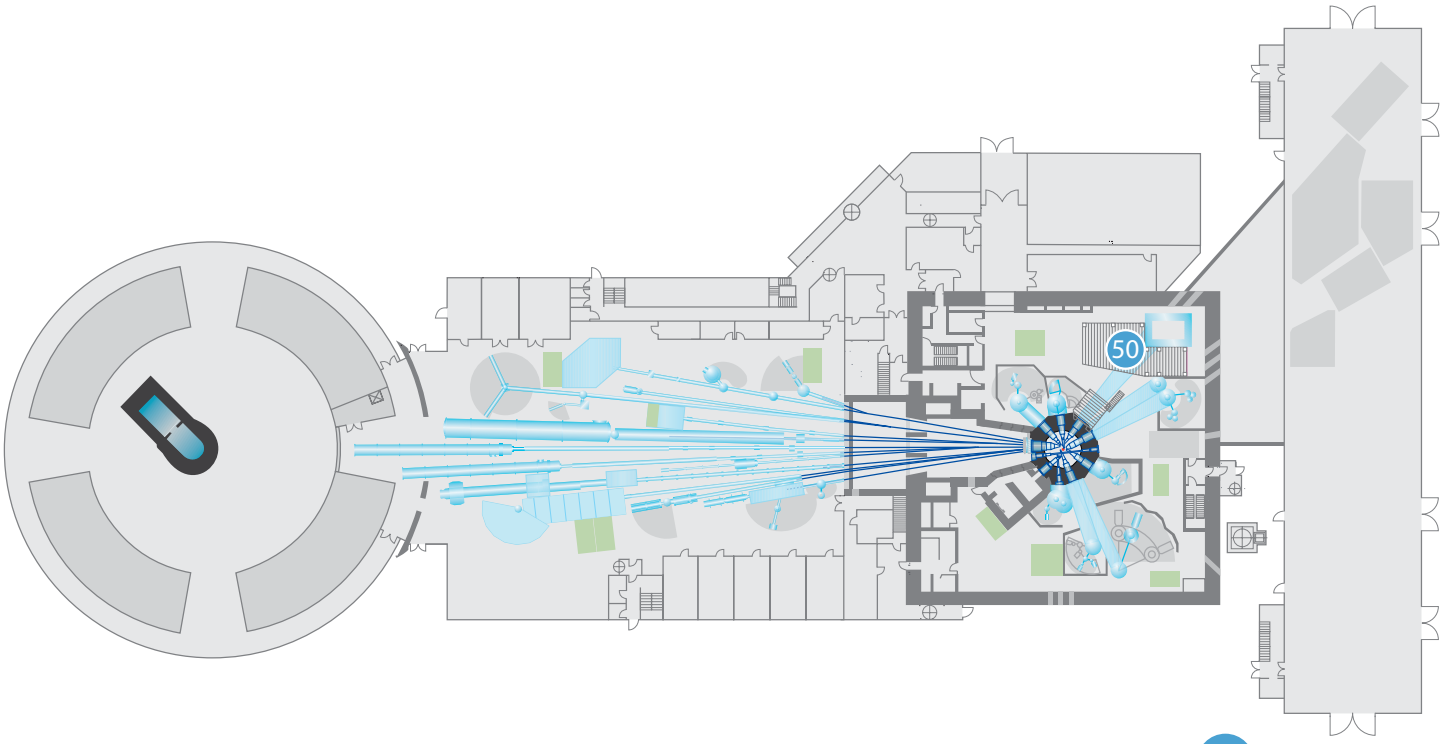
Figure 1: Selected examples of studies performed at Nectar

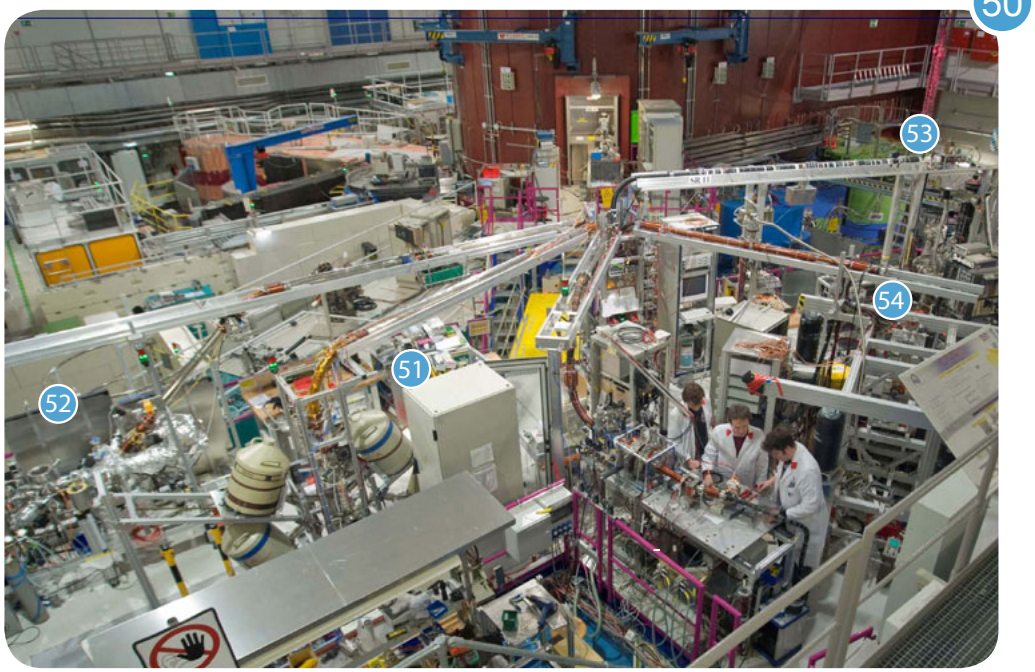
Dr. Thomas Bücherl

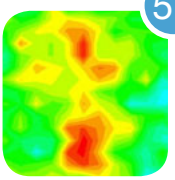
Phone: +49.(0)89.289.14328
Email: thomas.buecherl@radiochemie.de

Phone Instrument: .14831

www.frm2.tum.de/nectar







51

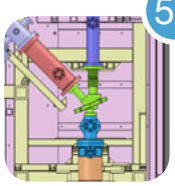
CDBS
coincident doppler-broadening spectrometer
p. 74

52

PAES
positron annihilation induced auger-electron spectrometer
p. 75

53

PLEPS
pulsed low energy positron system
p. 76



54

SPM
scanning positron microscope
p. 77

Positrons

NEPOMUC

neutron induced positron source munich

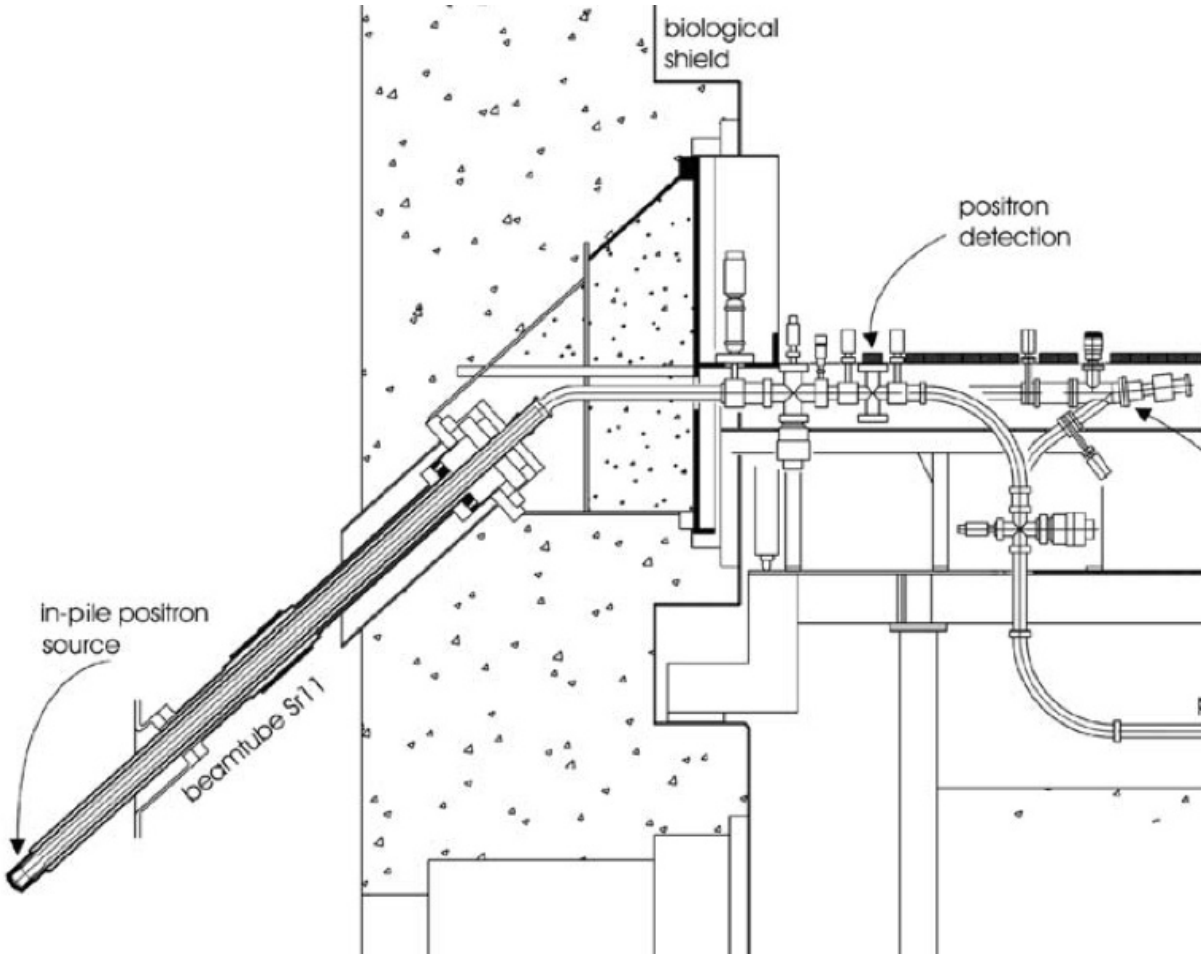


Figure 1: Cross-sectional view of the inclined beam tube SR11: the in-pile positron source is mounted inside the tip. After acceleration, the positron beam is magnetically guided to the remoderation unit outside the biological shield of the reactor.

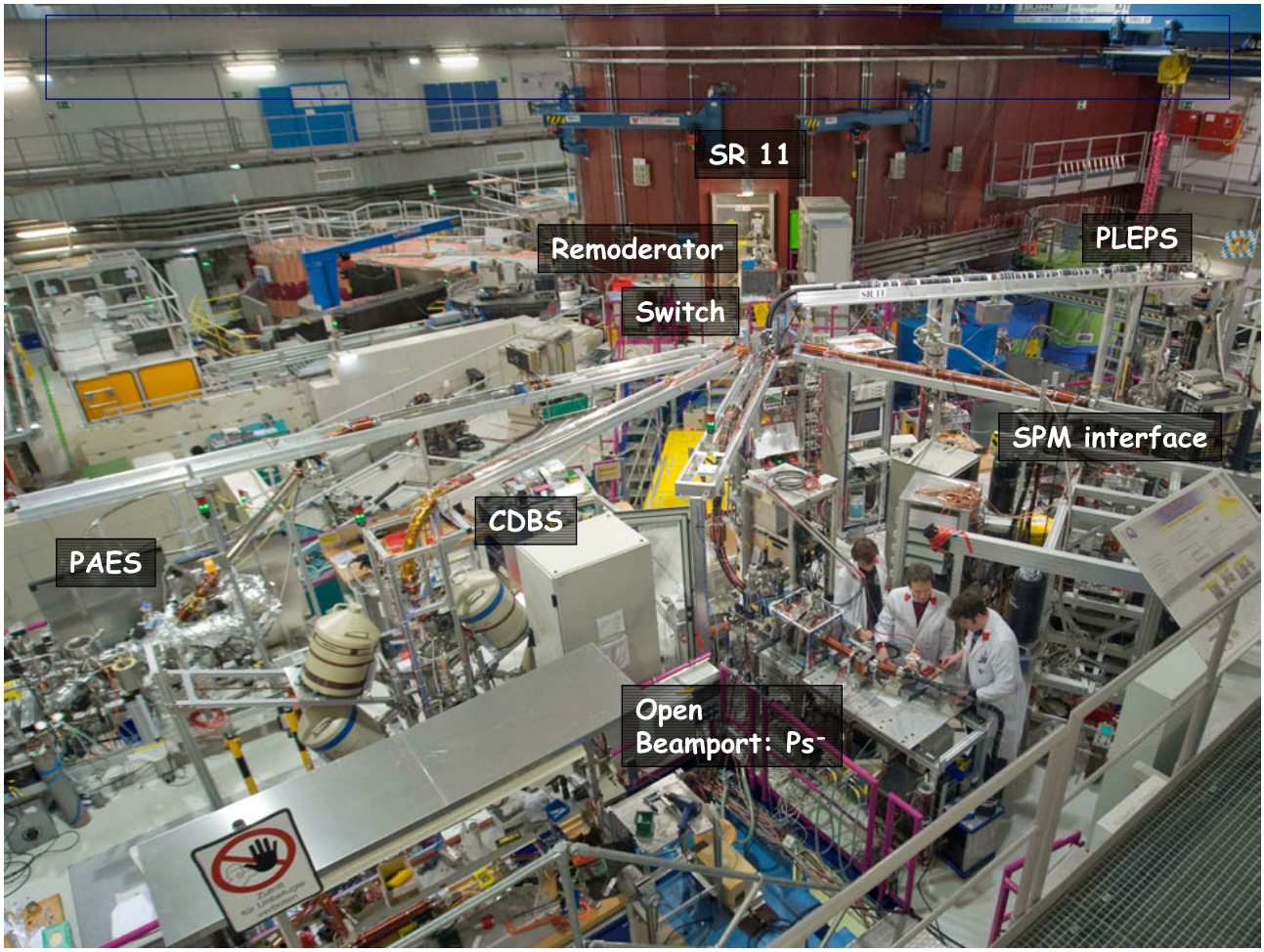
NEPOMUC – the NEutron induced POsitron source MUniCh

NEPOMUC provides a high-intensity low-energy positron beam for applications in solid state and surface physics as well as for fundamental research in nuclear and atomic physics.
At NEPOMUC, the positrons are generated by pair production from absorption of high-energy prompt gamma-rays after thermal neutron capture in Cd. A cadmium cap is mounted inside the tip of the inclined beamtube SR11 of the research reactor FRM II. The released high-energy gamma-radiation is converted into positron–electron pairs in a structure of platinum foils which is mounted inside the cadmium cap. Positive high voltage is applied in order to extract the moderated positrons. The positron beam is magnetically guided in a solenoid field of typically 7 mT.

Technical Data

Key values of the primary positron beam

- E = 1 keV
- Intensity:
  $9 \cdot 10^8$ moderated positrons per second
- Diameter of beam spot:
  7 mm (FWHM) in 7 mT beam guiding field.



The positron beam facility

The primary positron beam is guided to a positron remoderation unit, which is operated with a tungsten single crystal in back reflection geometry. This device has been implemented in order to improve the beam brightness.
Via a beam switch the positron beam can be guided to 5 different experimental beam ports.
At present, three instruments are in routin operation:

- Pulsed low-energy positron system (PLEPS)
- Coincident Doppler-broadening spectrometer (CDBS)
- Positron annihilation induced Auger-electron spectrometer (PAES)

An interface containing pulsing and remoderation units is currently installed for the:

- Scanning Positron Microscope (SPM)

The multi-purpose open beamport is used for transportable short-term experimental setups. At present, an apparatus for the production of the negatively charged positronium ion is connected to the beamline.

Technical Data

Key values of the remoderated positron beam

- E = 20 eV
- Intensity:
  3-5 $\cdot 10^7$ remoderated positrons per second
- Diameter of beam spot:
  2-3 mm (FWHM) in 7 mT beam guiding field

Dr. Christoph Hugenschmidt

Phone: +49.(0)89.289.14609
Email: christoph.hugenschmidt@frm2.tum.de

Phone Instrument: .14774

www.frm2.tum.de/nepomuc

CDBS

coincident Doppler-broadening spectrometer

Description

The Doppler broadening of the 511 keV annihilation line contains information of the electron momentum distribution at the positron annihilation site in the sample. Since the probability of core electron annihilation decreases in open volume defects a narrowing of the annihilation line is observed.
For this reason, DBS with the monoenergetic positron beam allows to determine defect profiles, energy dependent 2D imaging of defects, and defect annealing as a function of temperature. In addition CDBS is applied in order to gain elemental information about the positron annihilation site and hence about the chemical surrounding of defects.

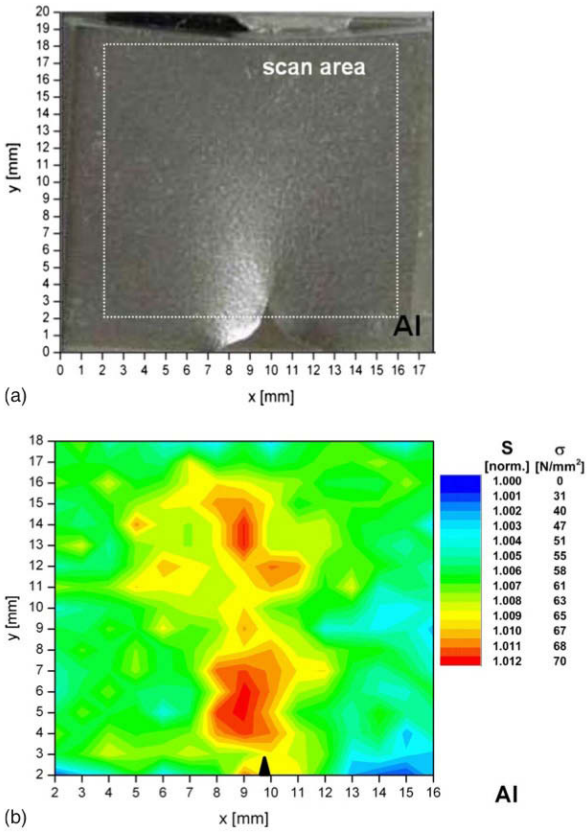


Figure 1: 2D defect map of an plastically deformed Al sample (below) and optical image (above).

Technical Data

Beam properties

- Positron implantation energy: E = 0.2 – 30 keV
- Mean positron Implantation depth: up to several µm (material dependent)
- Beam size: adjustable between 0.3 – 3 mm Ø

2D x-y-scans

- scan area: 20 × 20 mm²
- step size adjustable between 0.1 and 10 mm

High-purity Ge detectors

- 30 % efficiency
- energy resolution: 1.4 keV at 477.6 keV
- (upgrade to 8 detectors in 2010)

Sample

- size up to 20 × 20 × 3 mm³
- optimum 4 samples at one sample holder: < 10 × 10 mm²
- Temperature: 100 K – 600 K

Typical measurement times

- ~ 1 – 2 min / spectrum
- ~ 8 h full 2D overview scan (with Δx = Δy = 1 mm)
- ~1 h depth profile (t = 2 min, 30 energy values)
- ~ 4 – 6 h/spectrum CDBS

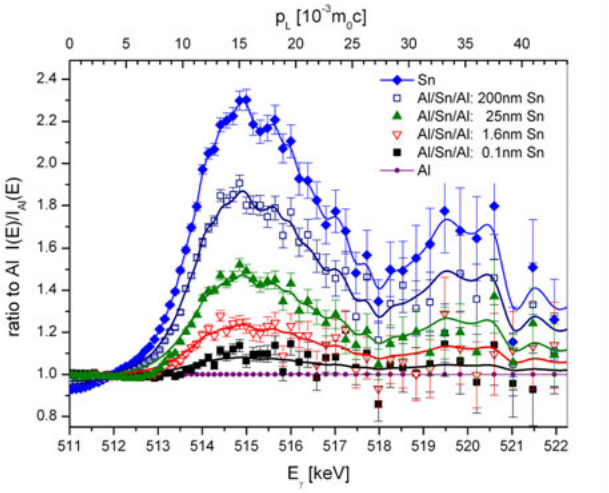
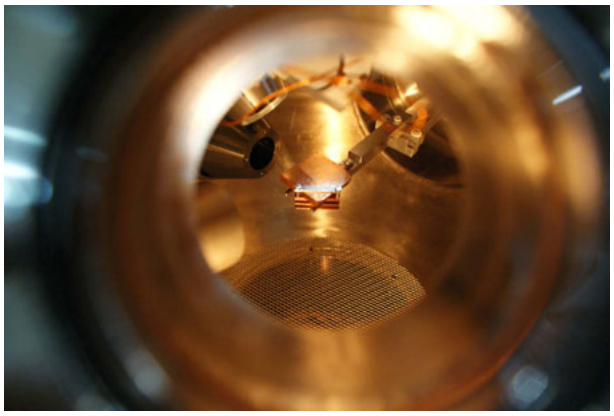


Figure 2: Thin Sn layers of various thickness buried in an Al matrix: Ratio curves recorded with CDBS reveal the elemental signature of layered samples.

PAES

positron annihilation induced Auger-electron spectrometer



Description

PAES is a newly developed application for surface studies with high elemental selectivity and exceptional surface sensitivity. In PAES the emission of Auger electrons is initiated by positron-electron annihilation that leads to several major advantages, e.g. topmost layer sensitivity, compared with conventional electron induced AES.
Examples are surfaces with sub-monolayers of foreign atoms, high resolution determination of Auger line shapes, element selective surface studies.

Technical Data

Beam properties

- Positron Implantation Energy: 20 eV
- Electron energy resolution: ΔE/E <1 %

Sample

- Sample size: 20 x 30 mm^2
  (minimum size 10 x10 mm^2)
- Sample thickness: max. 3mm

Typical measurement times

- Measurement time (typically): 10^{-15} min.

Complementary techniques

- Conventional Electron induced AES
- XPS/XAES and STM (implemented in 2010/2011)

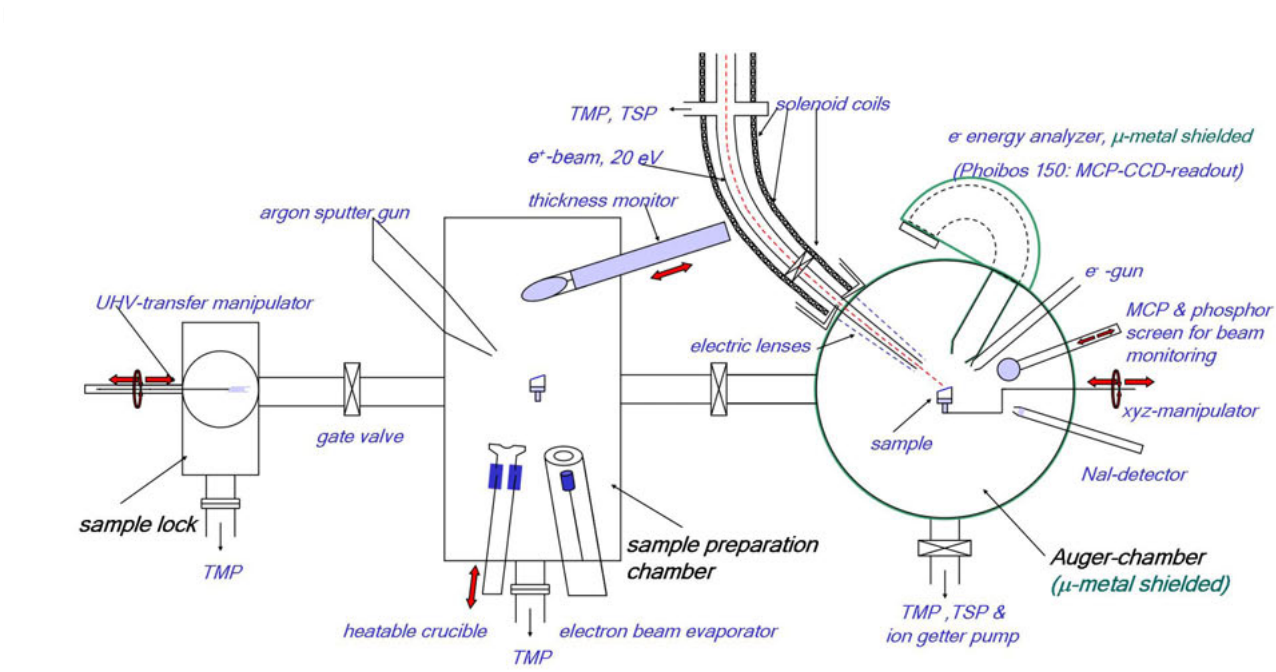


Figure 1:Sketch of the Auger sample chamber with sample preparation chamber and lock

Dr. Christoph Hugenschmidt

Phone: +49.(0)89.289.14609
Email: christoph.hugenschmidt@frm2.tum.de

Phone Instrument: .14774

www.frm2.tum.de/nepomuc

PLEPS

pulsed low energy positron system

Description

Positron lifetime measurements allow to determine defect size and concentration in metals, insulators and semiconductors as well as the free volume in polymers. Main application of PLEPS at NEPOMUC is the study of defect profiles in thin films and thin polymers.
Recently, first age-momentum correlation measurements (AMoC) were performed.

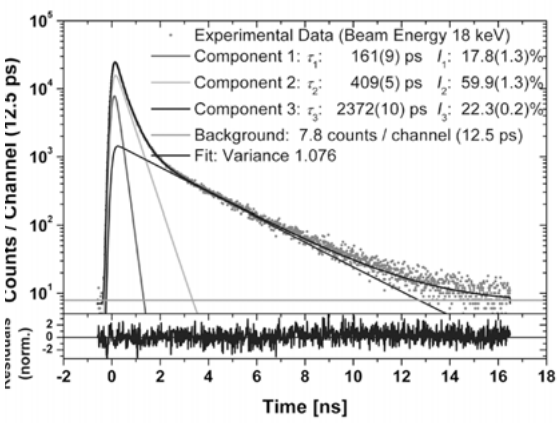


Figure 1: Typical positron lifetime spectrum in an epoxy-based industrial adhesive. The positron implantation energy was 18 keV according to a mean implantation depth of 4 µm. The spectrum can be decomposed into three exponentials with three different lifetimes. From the longest lifetime of 2.3 ns the mean size of free volume cavities in the polymer is estimated to be 0.13 nm³.

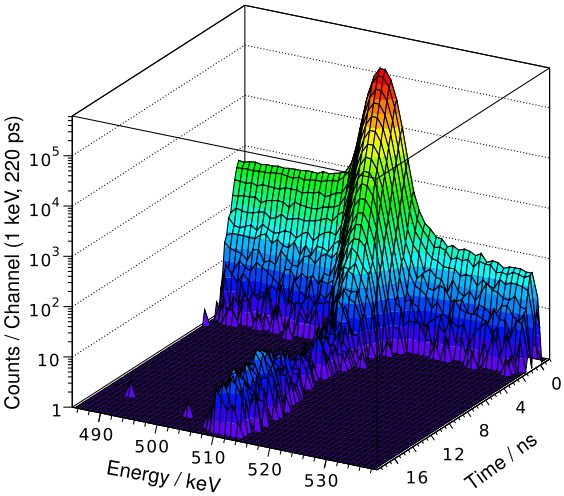


Figure 2: Age-Momentum Correlated (AMoC) spectrum in Kapton measured with a BaF_2 scintillation detector and a HP-Ge detector in coincidence. AMoC measurements contain information about the type of defect and its chemical environment, thus giving a more complete picture of the annihilation site than lifetime measurements and Doppler broadening measurements alone.

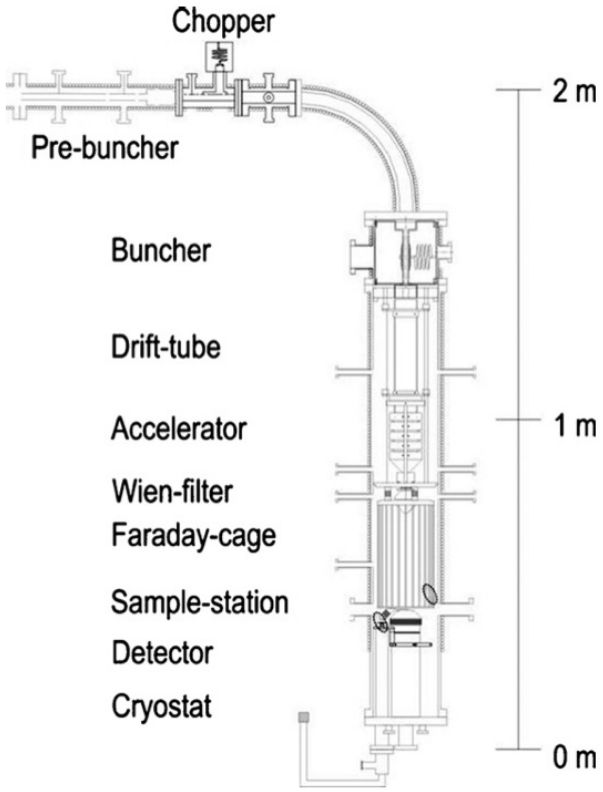


Figure 3: The components of PLEPS

Technical Data

Beam properties

- Positron implantation energy: 0.5 – 20 keV
- Beam-Spot Ø 2 – 3 mm
- Count rate: ~ 5000 – 10000 cps

Sample

- limited to 7 × 7 mm² – 9 × 9 mm²

Typical measurement times

- < 10 min per spectrum
  (> 3 · 10⁶ counts in the spectrum)
- Depth-profile: 4 – 5 h
  (15 – 20 implantation energies, > 3 · 10⁶ counts in the spectrum)
- Time-window: 20 ns, extension to longer time windows planned
- Time-resolution: 260 – 280 ps
- Peak / Background ~ 10000:1

der Bundeswehr Universität München

Dr. Werner Egger

Phone: +49.(0)89.289.12299 (office TUM)
+49.(0)89.6084.3007 (office UniBW)
Email: werner.egger@unibw-muenchen.de

SPM

scanning positron microscope

Description

The Munich scanning positron microscope (SPM) is presently operated at the Universität der Bundeswehr München. It permits positron lifetime measurements with a lateral resolution in the µm range and within an energy range of 1-20 keV. Thus, this instrument enables the measurement of high resolved 3D defect maps. One practical limitation of the SPM is set by the long measurement times of several days per 2D-scan due to the low intensity of the positron beam produced by a standard ^{22}Na source. This disadvantage will be overcome by installing the SPM at the high intensity positron beam at NEPOMUC.
Therefore, an interface was designed and tested successfully (see figures). This device converts the continuous beam of NEPOMUC to a high-brightness, pulsed positron beam, which matches the demands of the SPM. Recently, a triply moderated positron beam was generated. Currently, a beam "elevator" unit is under construction in order to connect the optical column of the SPM with the interface.

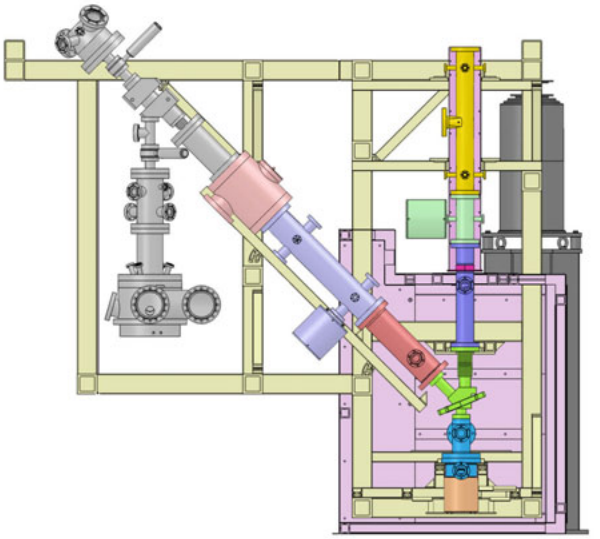


Figure 2: The optical column of the SPM (light gray) connected to the SPM interface. Both is borne by a special frame construction (light yellow), which ensures the vibration decoupling via heavy damper (dark gray, only one shown).

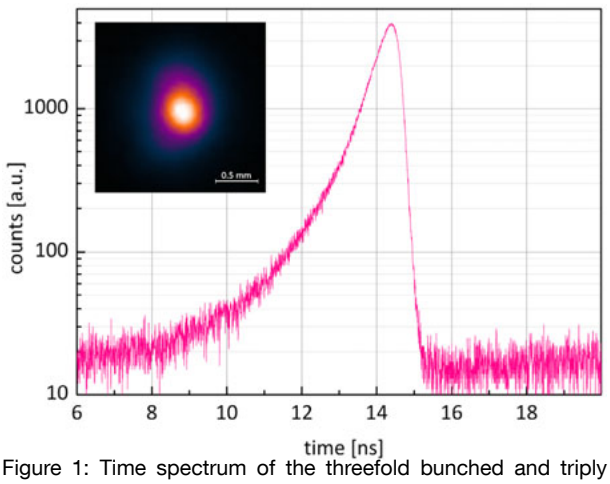


Figure 1: Time spectrum of the threefold bunched and triply moderated positron beam.
Insert: intensity distribution of the beam focused by a long focal electric lens.

Technical Data

Beam properties

- Positron implantation energy: < 20 keV
- Beam-Spot < 1 µm
- Count rate: > 2000 cps
- Time-Window: 20 ns
- Time-Resolution: <250 ps
- Peak / Background > 5000:1

Typical measurement times

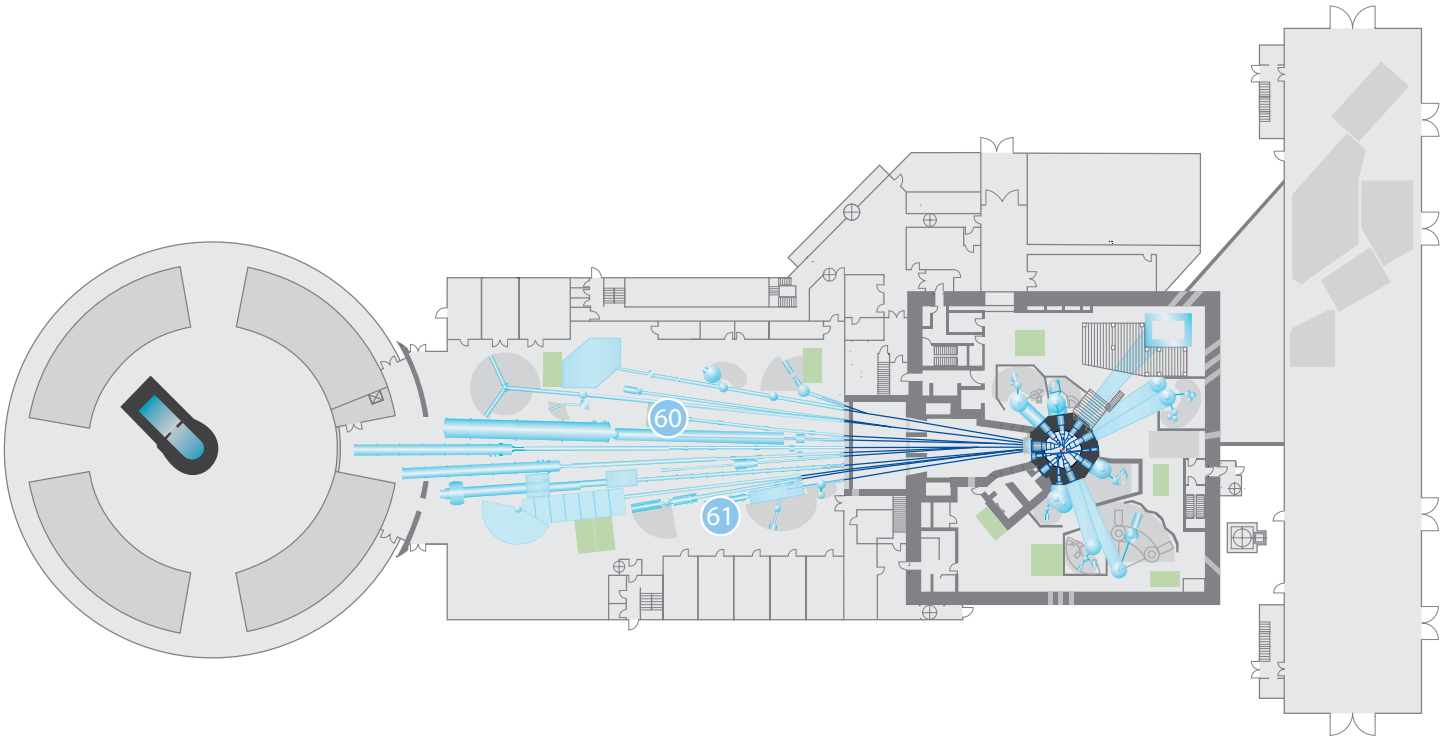
- ~ 1 day for one 2D-Scan (12 x 12 µm^2)

Universität der Bundeswehr München

Dr. Christian Piochacz

Phone: +49.(0)89.289.12179
Email: christian.piochacz@frm2.tum.de

Technische Universität München



60

PGAA
promt gamma activation analysis
p. 80 / 81

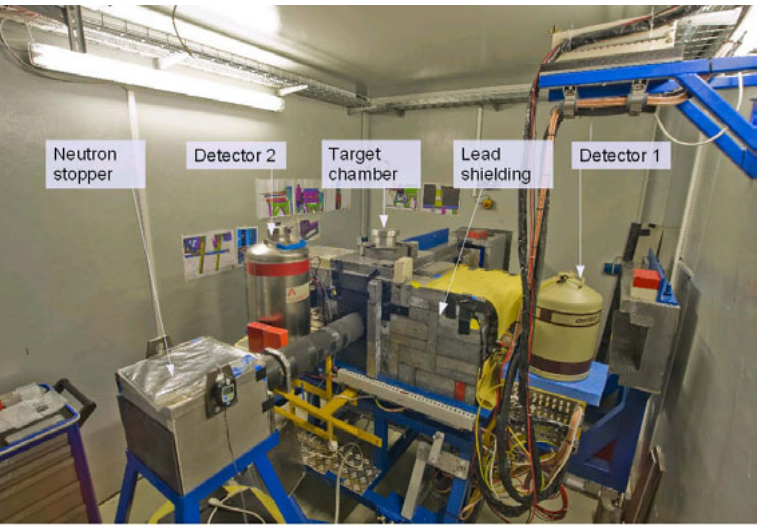
61

MEPHISTO
facility for particle physics with cold neutrons
p. 82 / 83

Nuclear and Particle Physics

PGAA

prompt gamma activation analysis



Description

Prompt Gamma-Ray Activation Analysis (PGAA) is typically used for the determination of elemental composition and concentration of solid samples (ca. down to ppm range). Liquids and gaseous samples can be also measured.

The PGAA method is based on the neutron capture in nuclei of the sample material and the subsequent detection of prompt gamma-rays emitted during deexcitation of the compound nuclei: $^{A}Z(n, \gamma)^{A+1}Z$.

With practically the same PGAA set-up (after minor or major changes in electronics or/and shielding and sample chamber), we can make coincidence measurements and position sensitive measurements (currently 1D or 2D scan).

Typical Applications

- Archaeology and cultural heritage objects (ceramics, coins, metals, conditionally bronze objects)
- Cosmochemistry (meteorites)
- Geology, petrology (macerals, sediments)
- Medicine (B, Li, Cd in tissues, nano-particles for cancer therapy, radiation damage of DNA)
- Semiconductor or superconductor research and industry
- Analysis of new chemical materials (catalysts, clathrates, crystals)
- Reactor physics (shielding material, new fuel element), radiation hardness testing with cold neutrons (chips, scintillators)
- Fundamental research (low-spin excited states in nuclei, neutron capture cross-section measurements), …

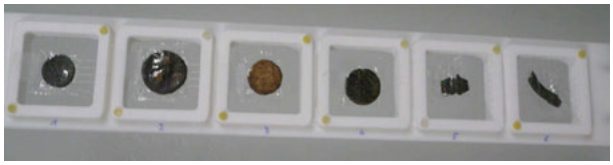


FIgure 1: Six pieces of Greco Roman bronze coins and objects (1st century AC) sealed into FEP foils and mounted at the FEP ladder for the automated PGAA measurement (one FEP frame is 5 cm × 5 cm large).

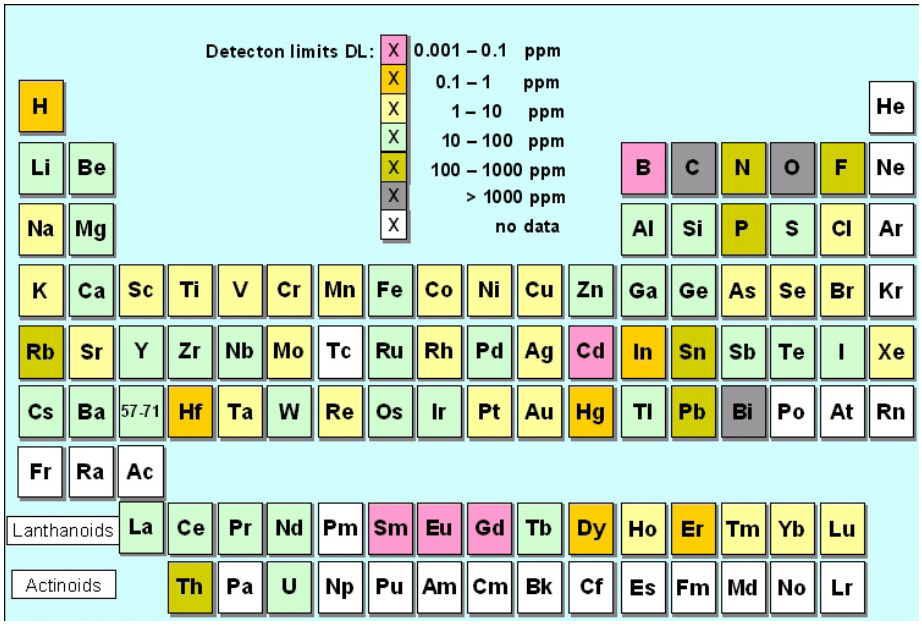
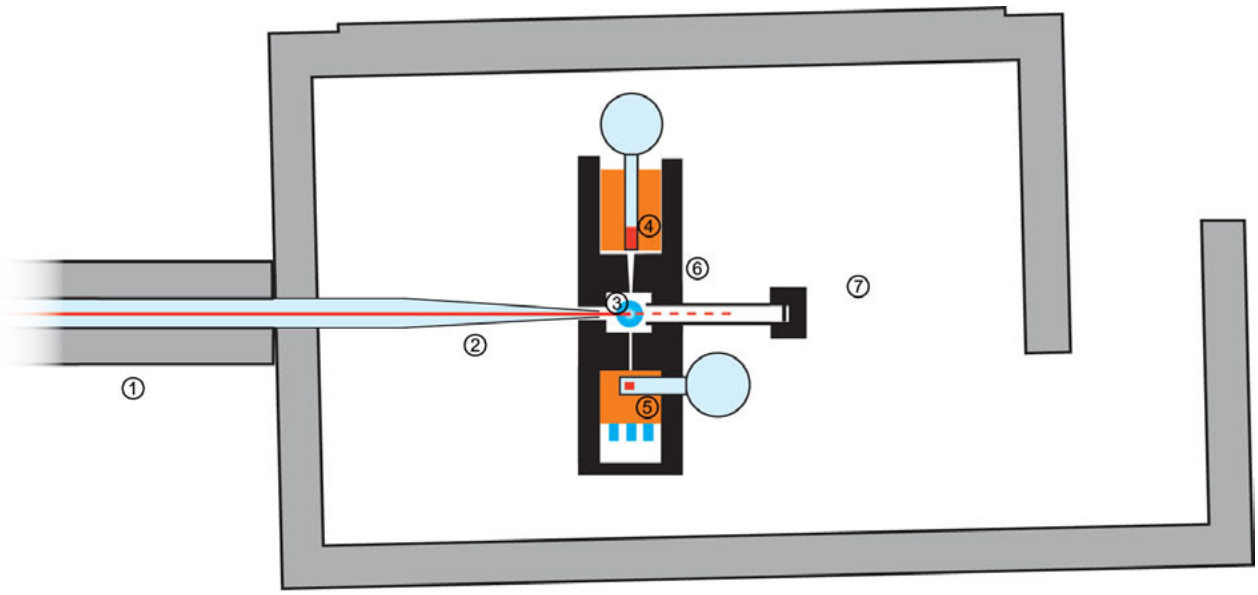


Table 1: This table gives the first estimate for the detection limits of the PGAA technique. The detection limits are mostly located in the ppm (µg/g) region and they are strongly dependent on the matrix of the sample material (detection limits with dynamic range).



① Neutron guide NL4b
② Optional elliptical focussing guide
③ Sample space
④ Detector D1 (HPGe 60%)
⑤ Detector D2 (HPGe 36%)
⑥ Pb shielding box
⑦ Beam stop

Technical Data

Neutron beam

Cold neutron spectrum from NL4b (last section of 5.8m elliptical focussing) with an average energy of 1.83 meV (6.7 Å).
Two measuring positions:

- P1 (larger samples):
  Beam size: 34 × 48 mm^2
  Neutron flux: max. 6.5 · 10^9 n/cm^2s
  (2.4 · 10^{10} n/cm^2s thermal n. eq.)
- P2 (small samples)
  with optional 1.1m elliptical guide
  Beam size: 16 × 19 mm^2
  Neutron flux: max. 1.6 · 10^{10} n/cm^2s
  (6.1 · 10^{10} n/cm^2s thermal n. eq.)

Detection system

Two Compton-suppressed spectrometers (HPGe detectors: D1 60% and D2 36%; surrounded with NaI(Tl)/BGO and BGO scintillators respectiviely and connected in anticoincidence mode). Analogue electronics (NIM modules) and multichannel analyzer with integrated ADC.
Detection range of typically 80keV – 11 000keV (adjustable)

Measuring conditions

- Low vacuum (~0.5 mbar) possible
- Sample weight: units of mg – g
- Max. sample dimensions:
  ca. 40 × 40 x 40 mm^3
- Automated measurement for max. 6 samples in a batch (vertical sample holder with 6 positions)
  Solid samples are usually sealed in thin FEP bags

.

Data acquisition and analysis

- Linux based self developed software for the automated measurement of up to 6 samples in a batch run.
- Evaluation of the spectra and the calibration of the spectrometer (efficiency curve and non-linearity) using the software Hypermet PC developed in Budapest.
- Determination of the elemental composition of samples using the Excel macro and Excel sheet package ProSpeRo.

Dr. Petra Kudejova

Phone: +49.(0)89.289.14765
Email: petra.kudejova@frm2.tum.de

Phone Instrument: .14906

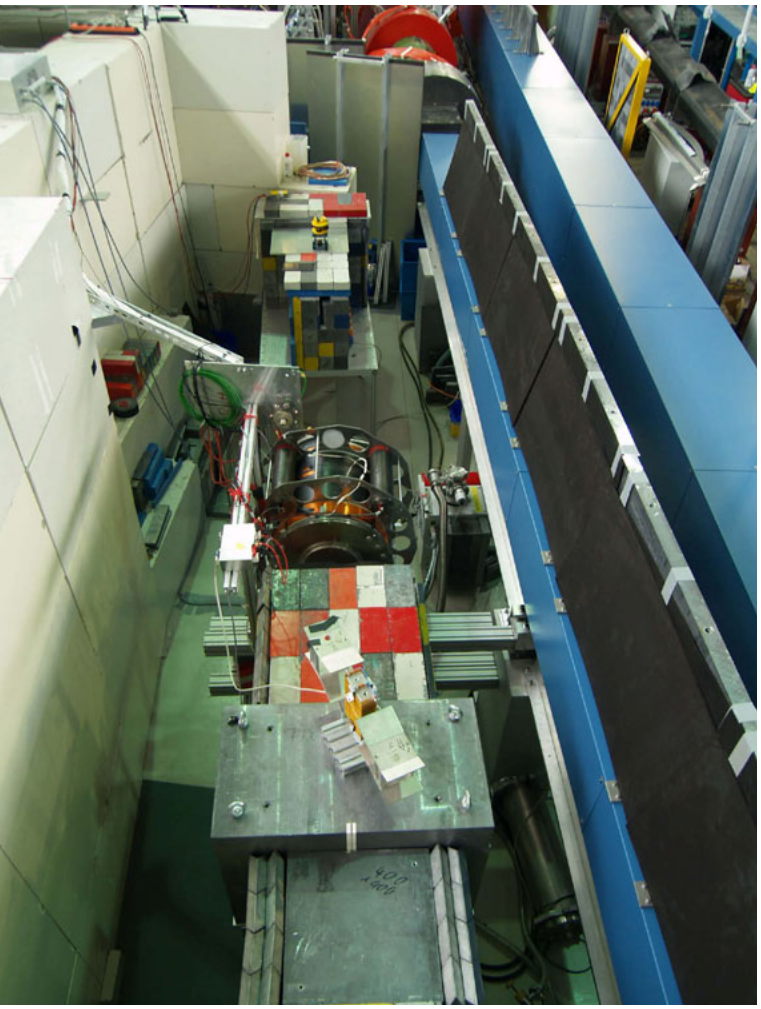
Dipl. Phys. Lea Canella

Phone: +49.(0)89.289.14758
Email: lea.canella@frm2.tum.de

www.frm2.tum.de/pgaa

MEPHISTO

facility for particle physics with cold neutrons



Description

The experimental area MEPHISTO (measurement facility for particle physics with cold neutrons) is placed at the end of the cold neutron guide NL1, which provides a cold neutron spectrum with an total flux of about 5.25 10^9 s^{-1} (see figure 1).

Most of the experiments at MEPHISTO are precision experiments in the field of nuclear and particle physics. All experiments which need a white cold neutron guide as source can be performed at MEPHISTO.

An experiment is normally planned and build up by an external group. The FRM II will offer additional help during the commissioning of the experiment at the reactor. This work must be organised in close contact with the local instrument responsible. The desired precision is reached by good statistics which means long term experiments about several reactor periods.
In the next years the experimental area MEPHISTO will move in the new neutron guide hall east to offer more space for large experiments and higher flux.

Typical Applications

The experiments at MEPHISTO concentrate on induced nuclear reactions of the neutron with atoms or on the free neutron decay with its products.
Some of the experiment types performed at MEPHISTO:

- Free neutron decay and spectroscopy of the decay products
- Spectroscopy of neutron induced fission
- Production of ultra cold neutrons with liquid helium
- Production of ultra cold neutrons with solid gases

Infrastructure

A data system based on VME (peak ADC, QDC, TDC) is available. For signal forming purpose several NIM inserts exist, a list can be requested by the local instrument responsible. Also available are spectroscopic amplifiers and high voltage sources for detectors.

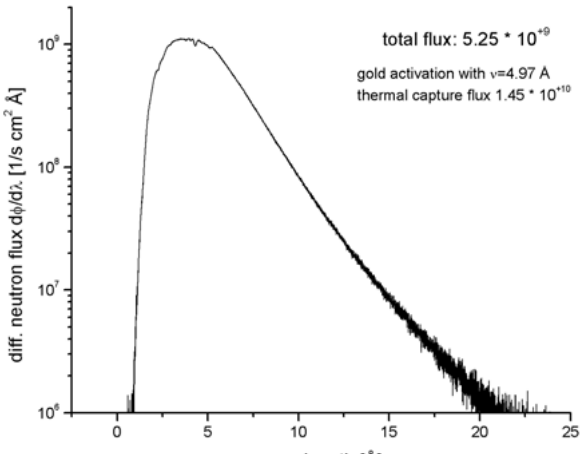
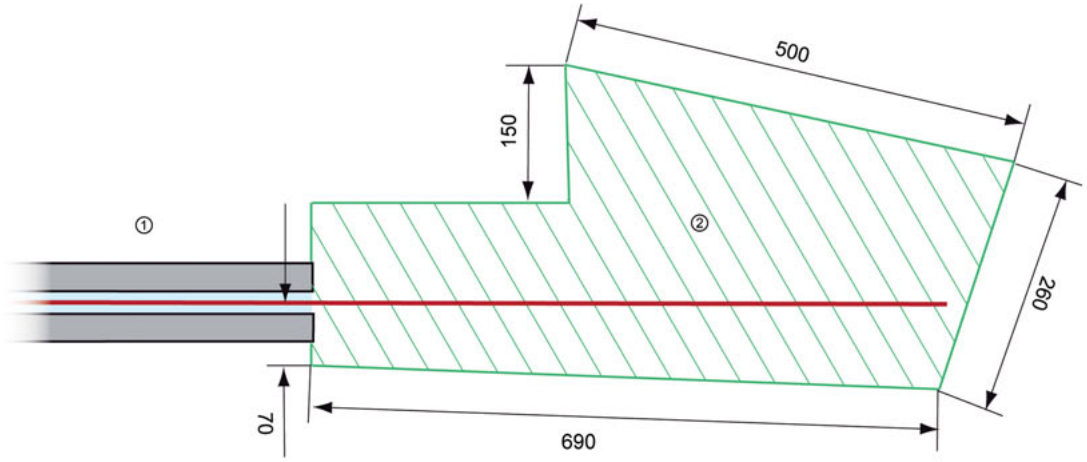


Figure 1: Cold neutron spectrum of the NL 1 at the MEPHISTO facility.



① Neutron Guide NL 1
② Experimental area

Technical Data

Neutron beam

- End of neutron guide NL 1 (m = 2)
- Cross section of the guide: 60 x 120 mm²
- Thermal capture flux: 1.45 · 10^{10} n $cm^{-1}s^{-1}$
- Mean wavelength 4.97 Å
- Beam height from floor: 1190 mm
- Distance to NL 2: 700 mm.

Beam attenuators

By geometrical attenuation, the beam intensity can by reduced to 20%, 4% and 2%.

Polarisation

A bender (vertical direction) is available to polarise the complete cross section of the beam.

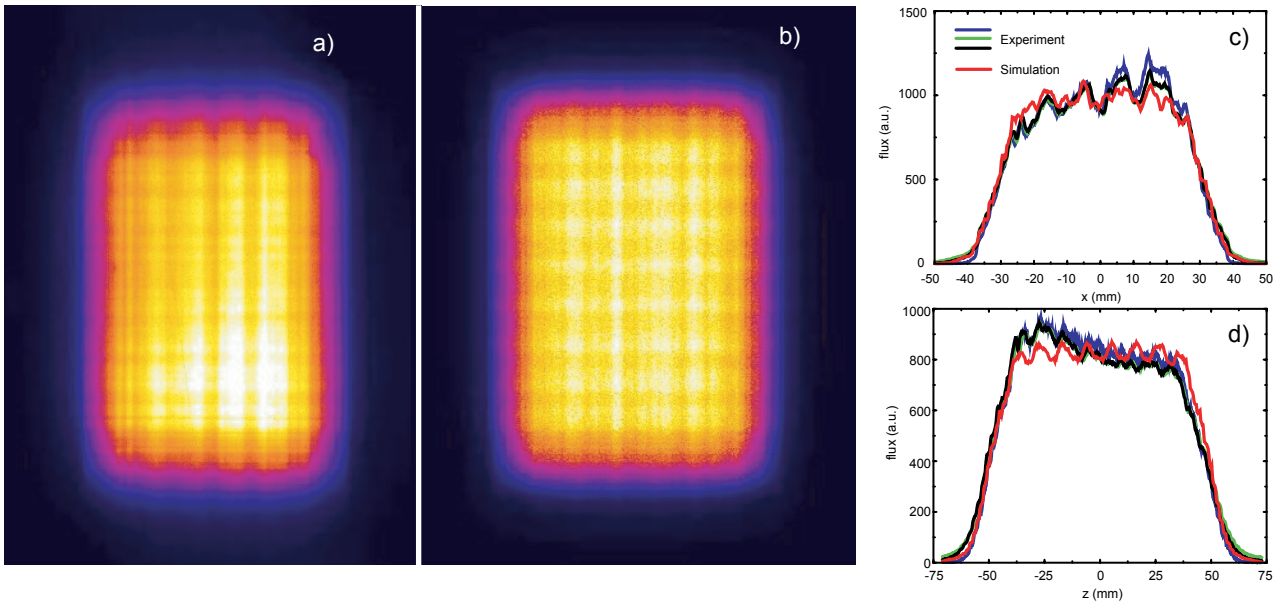


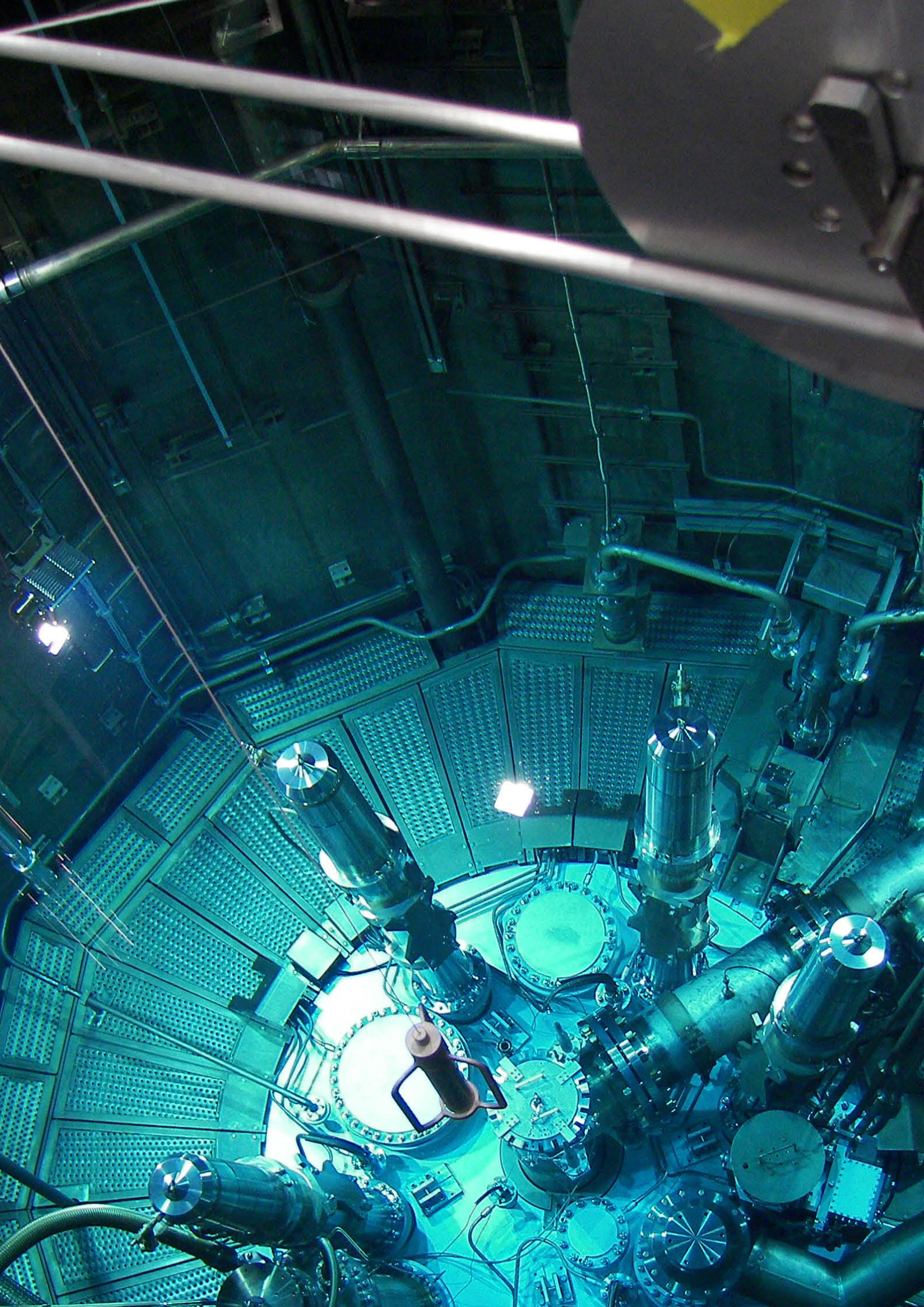
Figure 2: Neutron beam profile of NL 1 at the MEPHISTO facility: a) measured b) simulated c) horizontal integral d) vertical integral.

Dr. Jens Klenke

Phone: +49.(0)89.289.14771
Email: jens.klenke@frm2.tum.de

Phone Instrument: .14879

www.frm2.tum.de/mephisto



Irradiation facilities

Irradiation facilities

The irradiation of materials serves many purposes including the doping of silicon and the production of radioisotopes for industry and medicine, as well as the examination of samples with neutron activation analysis.
The neutron source FRM II is equipped with a series of irradiation facilities, which cover a wide range of applications both with regard to the available sample volumes and the achievable neutron fluences.
For proposals and experiments dealing with the irradiation facilities please contact directly the responible of the irradiation services Dr. Heiko Gerstenberg.

Standard rabbit irradiation system (RPA)

Six independent irradiation channels are available with the standard rabbit irradiation system. The positions are vertically staggered in the moderator tank, allowing for the selection of a thermal neutron flux density adapted to the sample. The flux densities range from $5 \cdot 10^{12}$ to $4 \cdot 10^{13}$ $cm^{-2}s^{-1}$. Sample sizes should be less than 12 cm^3. They are packed in polyethylene capsules and conveyed pneumatically by CO_2 into the irradiation position. The available thermal neutron fluence varies between $2 \cdot 10^{14}$ cm^{-2} and $3 \cdot 10^{17}$ cm^{-2}. For the various irradiation channels the ratio of thermal/fast neutron flux density is as high as 15000 – 60000.

Capsule irradiation facility (KBA)

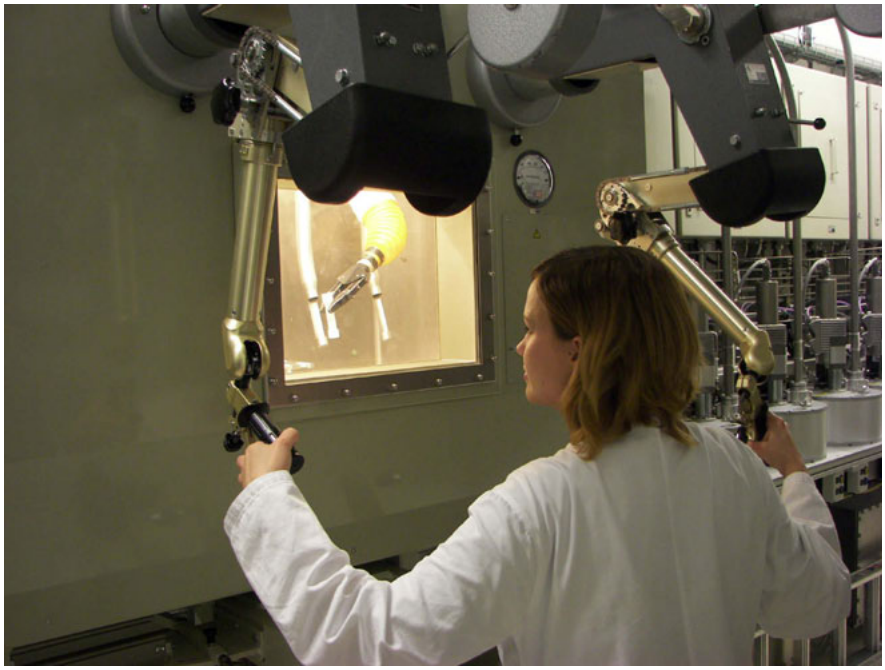
High dose irradiation spanning periods from several hours to weeks, is carried out in the capsule irradiation facility. It is a pool water-operated hydraulic rabbit system with two mainly identical irradiation channels exhibiting neutron flux densities of up to $1.3 \cdot 10^{14}$ $cm^{-2}s^{-1}$. The samples are packed in aluminium capsules with a volume of up to 30 cm^3. If required, the samples are packed water tight in an inner capsule from high purity aluminium or quartz. Up to five capsules may be irradiated simultaneously in each run of the irradiation facility. The ratio of thermal/fast neutron flux density ranges between 330 and 770.

Mechanical irradiation system

Samples sized up to 2.5 litres can be irradiated in a facility in the moderator tank. In spite of the available sample size of 2.5 l the facility is typically used for short term irradiations of smaller samples. The thermal neutron flux density is $1.1 \cdot 10^{13}$ cm^{-2} s^{-1}. The maximum licensed irradiation time is 2 h corresponding to a thermal neutron fluence of $8 \cdot 10^{16}$ cm^{-2}.

Irradiation position in control rod

The highest possible fluence of $1.1 \cdot 10^{21}$ cm^{-2} can be reached at the irradiation position within the control rod. It is only possible, however, to load and unload it when the reactor is shut down, after the completion of its 60-day cycle.



After irradiation in the rabbit system, the samples are prepared via manipulators to be sent to the customers.

The standard rabbit irradiation system has six independent irradiation channels and is operated by carbon-dioxide.

Gamma-ray irradiation facility

In order to use the very strong gamma radiation within the spent fuel elements, a new gamma-ray irradiation facility is under construction. It is supported by the German Research Association (Deutsche Forschungsgemeinschaft: DFG) and will be located in the storage rack of spent fuel elements. The typical gamma dose rate ranges from 1 kGy/h up to 100 kGy/h. The sample container has a diameter of 85 mm and a height of approximately 1 metre. Additionally, the sample position can be heated up to 150 °C, if required. The activation of samples during the irradiation can be neglected. The irradiation time can vary between several minutes to several weeks.

Irradiation with fast neutrons at MEDAPP

As its name indicates, MEDAPP is mostly used for medical applications, as the irradiation of tumours and biomedical research on various cell strains. Furthermore, technical samples as micro-electronics can be irradiated with a fluence of up to about 10^{14} cm^{-2}. The flux of fast neutrons is between $2 \cdot 10^{8}$ and $7 \cdot 10^{8}$ cm^{-2} s^{-1} depending on the filtering; the maximum beam area is 300 × 200 mm^2.
Leaving out the converter plates, the beam tube SR10 delivers an especially pure thermal neutron beam with maximum flux of $3.9 \cdot 10^{9}$ $cm^{-2}s^{-1}$ on a rather large area up to 230 × 180 mm^2. It allows for, e.g., the irradiation of large etch track films. The access to the corresponding irradiation position on the lid of the beam tube, however, is restricted due to radiation protection.

Technical data

Standard rabbit irradiation system

- $5 \cdot 10^{12}$ to $4 \cdot 10^{13}$ thermal neutrons $cm^{-2}s^{-1}$
- ϕ_{th} / ϕ_f: 15000 – 60000

Capsule irradiation facility

- up to $1.3 \cdot 10^{14}$ thermal neutrons $cm^{-2}s^{-1}$
- ϕ_{th} / ϕ_f: 330 – 770

Mechanical irradiation system

- $1.1 \cdot 10^{13}$ thermal neutrons $cm^{-2}s^{-1}$
- ϕ_{th} / ϕ_f: ~1200

Gamma ray irradiation facility

1 kGy/h up to 100 kGy/h

Irradiation position in the control rod

$2 \cdot 10^{14}$ thermal neutrons $cm^{-2}s^{-1}$

Irradiation with fast neutrons at MEDAPP

up to $7 \cdot 10^{9}$ fast neutrons $cm^{-2}s^{-1}$

Dr. Heiko Gerstenberg

Phone: +49.89.289.12145
Email: heiko.gerstenberg@frm2.tum.de

www.frm2.tum.de/industrie

Irradiation facilities

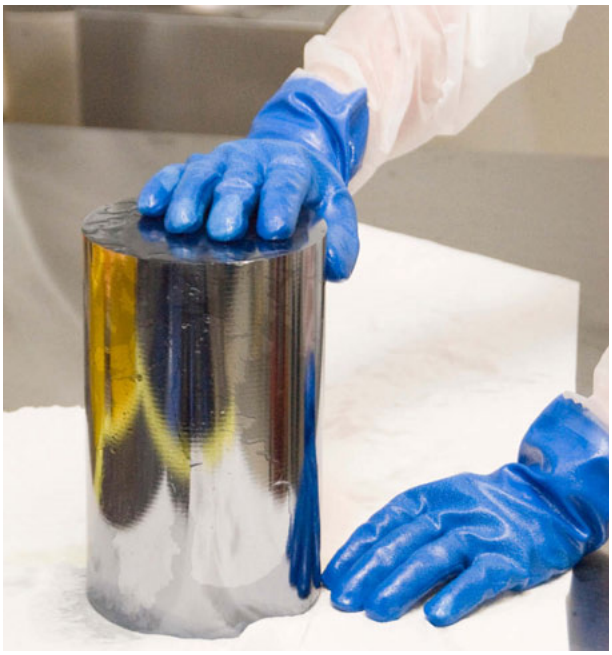


Figure 1: A silicon crystal after the doping at the FRM II neutron source.

Silicon doping facility

Pure silicon is a poor conductor of electricity. In order to gain the properties which make it interesting for components in the electro-technique, it needs to be doped with small amounts of host atoms e.g. phosphorous or boron. For high-performance electronic components as thyristors or IGBTs the Si needs to have a defined content of phosphorous atoms distributed extremely homogeneously within the Si matrix. At the FRM II silicon ingots (see fig. 1) up to a diameter of 200 mm and a height up to 500 mm are irradiated in a position within the moderator tank. The doping is achieved by neutron capture and the resulting conversion of individual ^{30}Si atoms into ^{31}P. Due to the neutron moderation by heavy water the facility is particularly useful for the production of high resistivity (up to 1000 Ωcm) neutron transmutation doped (NTD) Si. The silicon doping facility is automated and operated in two working shifts. The typical yearly output sums up to about 15 tons. The customers of the doped ingots are semiconductor producers from Europe and Asia.

Neutron Activation Analysis

Neutron activation analysis (NAA) is used to analyse element composition in a material (see fig. 2). Up to 30 or 40 elements can be determined simultaneously down to the ppt and sub-ppt range.
- Industrial applications:
- Trace elements in pure silicon
- Environmental monitoring, e.g. retained substrates in the filters of an exhaust of a chemical production

Figure 2: The NAA analysis includes the treatment of the materials after irradiation.

Figure 3: ^{177}Lu produced by the company ITG at the FRM II at the capsule irradiation facility. The radioisotope is filled in little vials with a volume of 2 ml and then packed in cans with a diameter of 45 mm and a height of 70 mm.

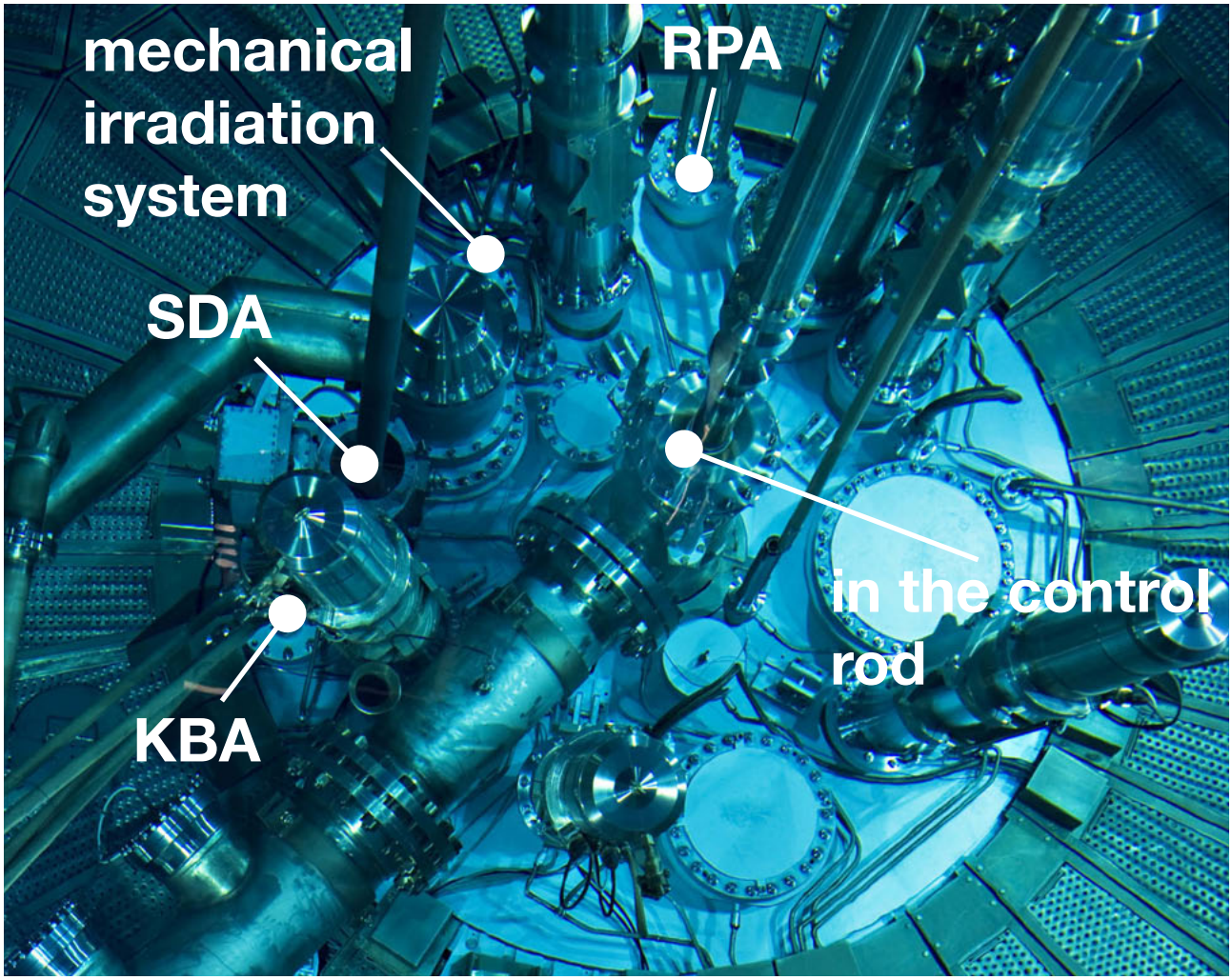


Figure 4: Positions of the different irradiation facilities within the reactor pool: RPA = rabbit irradiation system, KBA = capsule irradiation facility, SDA = silicon doping facility and irradiation position in the control rod.

- Archeological and geological applications:
- Fingerprint of materials gives clues about the origin of the findings
- Determination of the age and composition of rock by methods requiring reactor irradiation

Radioisotopes for medical and technical applications

Production of radioisotopes in the different facilities (e.g. KBA, RPA, fig. 4)

- ^{177}Lu, which is used for the therapy of neuroendocrine tumours (see fig. 3)
- ^{188}Re preventing local occlusions of blood vessels
- ^{60}Co for industrial purposes
- The production of ^{99}Mo at the FRM II is planned to start in 2014. Its daughter isotope ^{99m}Tc is used in more than 70 percent of all nuclear medical diagnoses.

Technical data

Silicon doping facility

- $1.7 \cdot 10^{13}$ thermal neutrons cm^{-2} s^{-1}
- Si dimensions: height ≦ 500 mm, ∅ = 200, 150, 125 mm
- ρ_{target}: 25 Ω cm - 1100 Ω cm

Neutron activation analysis

- Irradiation time: seconds - hours
- Sample weight: mg - g
- rel. efficiency at 1.3 MeV: >40%
- energy resolution: < 0.9 keV at 122 keV, < 1.8 keV at 1.3 MeV

Dr. Heiko Gerstenberg

Phone: +49.89.289.12145
Email: heiko.gerstenberg@frm2.tum.de

www.frm2.tum.de/industrie

SE
sample environment and user facilities
p. 92 / 93

HT
high temperatures

p. 94 / 95

LT
low temperatures

p. 96 / 99

HP
high pressure

p. 100

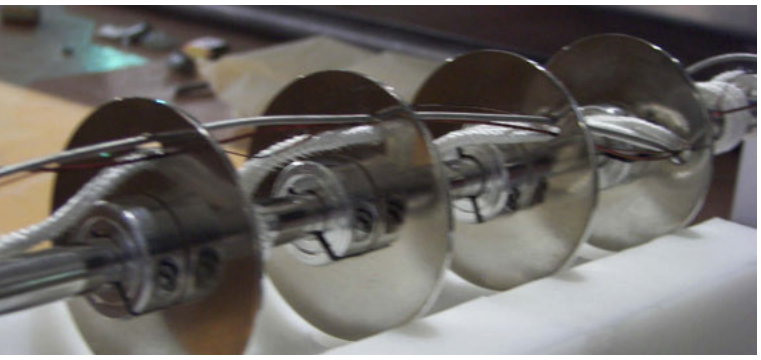
MF
magnetific field

p. 101

Sample environment

SE

sample environment and user facilities



High and low temperatures, pressure or load, magnetic fields

The provisioning of sample environment equipment for neutron scattering experiments is organized by a central service group at the FRM II. Today nine staff members are looking to fulfill the diverse needs of our users. A major part of the equipment is designed and fabricated or assembled in house. It ranges from a large variety of low temperature equipment down to 50 mK up to highest temperatures of nearly 2200 K. In addition, parameters like magnetic field and pressure or load can be applied to the sample under investigation. The equipment has been optimised for the application on neutron scattering instruments with a special emphasis on combining different parameters. As an example the high field vertical magnet with fields up to 7,5 Tesla can accept all kind of temperature inserts due to its large 100 mm diameter room temperature bore. Here low as well as high temperature devices can be introduced even with a pressure cell inside.
A detailed description of the available equipment is shown on the following pages. Furthermore, specialized environments are available at the different instruments, please see the respective sections. If a scientific project has special requirements, please do not hesitate to contact the sample environment group or your local contact for assistance.

Sample preparation laboratory and glove boxes

Treating the sample to a well defined state by means of our equipment during the experiment is some times not sufficient to characterize fully the state of the specimen. Therefore we can offer access to our sample preparation laboratory in the Neutron Guide Hall West for sample handling just before the experiment. Here you can find a high purity glove box or a fume cupboard to handle delicate sample material. Mobile glove boxes are installed in both experimental areas to be used close to the instruments.

Soft matter laboratory

Actually we are building up additional infrastructure for sample characterisation in connection with neutron or positron experiments. A newly equiped laboratory for soft matter including thermal characterisation and particle size distribution measurements (light and x-ray scattering) has been brought into operation recently.

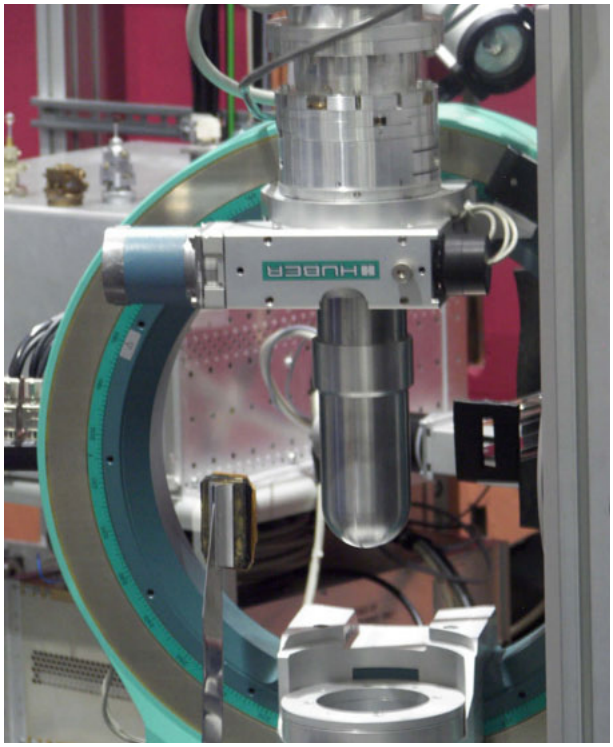
Further equipment

A high resolution transmission electron microscope will be available at the JCNS by the end of 2010. For the characterisation and fast orientation of single crystals a Laue camera will be installed on the thermal beam of the instrument RESI in the experimental hall. For the possibilities of additional in-situ measurements during your neutron scattering experiment, please refer to the instrument pages and contact the instrument scientists.

Mobile glove boxes are availble in both experimental areas.

The newly equipped laboratory for soft matter.

The laboratory for sample preparation in the neutron guide hall WEST.



Eulerian cradle with a closed cylce cryostat.

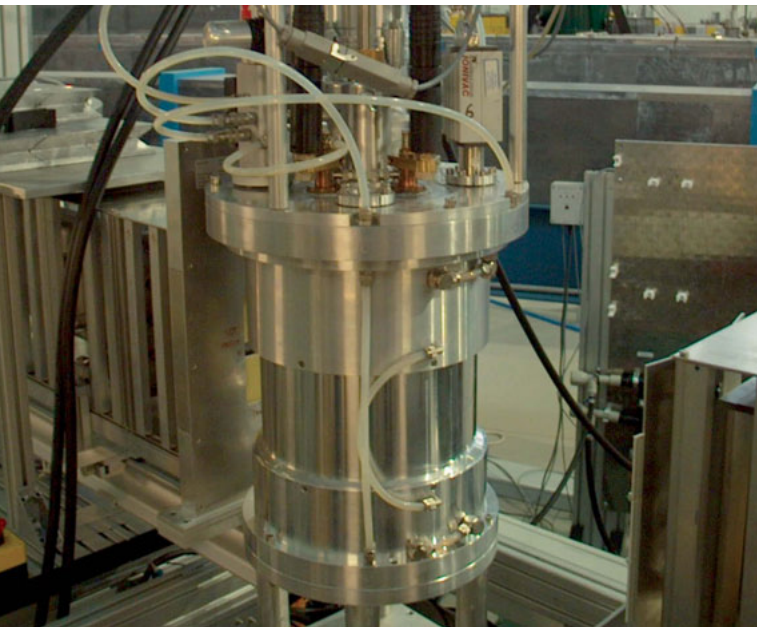
Dr. Jürgen Peters

Phone: +49.(0)89.289.14700
Email: juergen.peters@frm2.tum.de

www.frm2.tum.de/se

HT

high temperatures



Adapted to the needs of different applications and instruments, four types of high temperature furnaces are available.

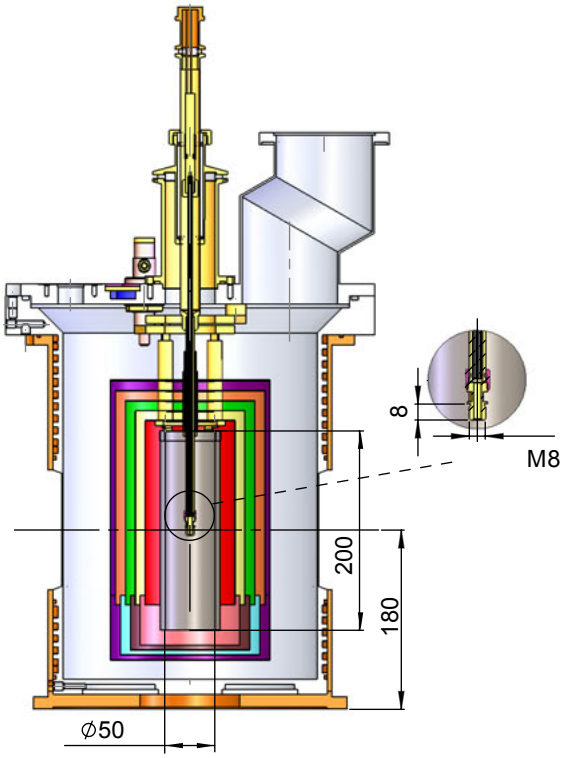


Figure 1: Cut through a standard HTF.

HTF - high temperature furnace

The heater of the HTF consist of a resistive Nb double cylinder element. Radiation shields made of Nb reduce the thermal loss. The sample is mounted on a sample rod top down, using a M8 screw. Maximum reachable temperature is 1900 °C. For temperatures up to 300 °C the furnace can be filled with Ar or He exchange gas to improve regulation stability. Temperature sensors are type C thermocouples.
Further a special version of the furnace with a reduced diameter for usage inside the CCM 7.5T vertical magnet is available.

IRF - Infrared light furnace

Compact dimensions are the key feature of the light furnace. The sample is placed at the focus of four halide lamps, therefore restricting the sample volume to a few mm³. The sample can be heated in vacuum or any convenient atmosphere up to ambient pressure respectively. Of course the maximum temperature depends on pressure.
A dedicated version of this furnace for use together with a load frame is availbale. Twelve halogen bulb lamps heat the sample up to 900 °C with an almost homogeneous temperature distribution. The sample volume has 6-8 mm diameter and 30 mm length. By means of an additional heat shield temperatures beyond 950 °C are expected.

PF - Polarised neutron furnace

For experiments using a polarized neutron beam a furnace with special bifilar heater cartridges is availble for the temperature range up to 700 °C.

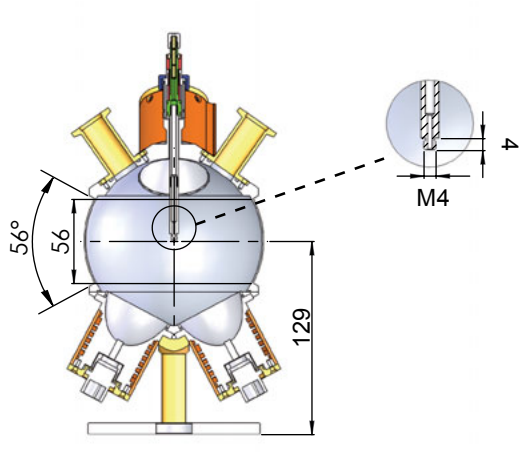
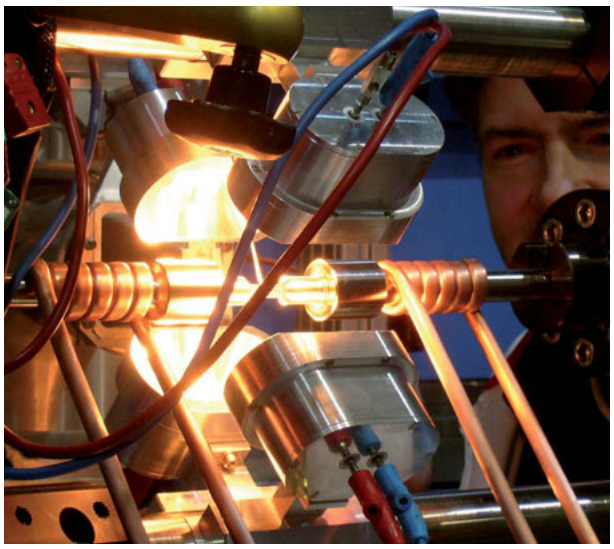


Figure 2: Cut through IRF light furnace.



CTF1- Circulation thermostat furnace

For the temperature range -20 °C to 200 °C a furnace using a thermalized cirulating medium allows for a precise regulation of the particularly homogenous sample temperature.

HTF technical details

Designation: HTF 1,2,3, 4-SPODI

- Temperature range (vacuum): RT – 1900 °C
- Temperature range (exchange gas): RT – 900 °C
- Thermometry: type C thermocouple
- Total height of sample space: 100 mm
- Diameter of sample space: 45 mm
- Sample rod tail: M8 (male)

IRF technical details

Designation: IRF 1,2

- Temperature range (vacuum): RT – 1200 °C
- Temperature range (Ar 100mbar): RT – 300 °C
- Thermometry: type K, R, S thermocouple
- Height of sample space: 15 mm
- Diameter of sample space: 10 mm
- Sample rod tail: M4 (male)

PF technical details

Designation: PF 1

- Temperature range (vacuum): RT – 700 °C
- Thermometry: Pt100
- Height of sample space: 80 mm
- Diameter of sample space: 45 mm
- Sample rod tail: M6 (male)

CTF

Designation: CTF 1

- Temperature range (vacuum): -30 °C – 200 °C
- Thermometry: Pt100
- Height of sample space: 80 mm
- Diameter of sample space: 48 mm
- Sample rod tail: M8 (male)

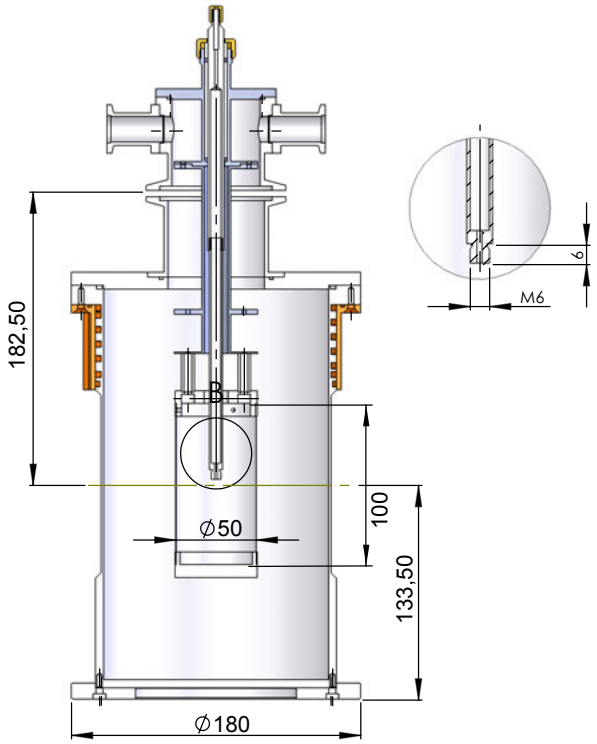


Figure 3: Cut through PF 1 furnace for polarized neutron experiments.

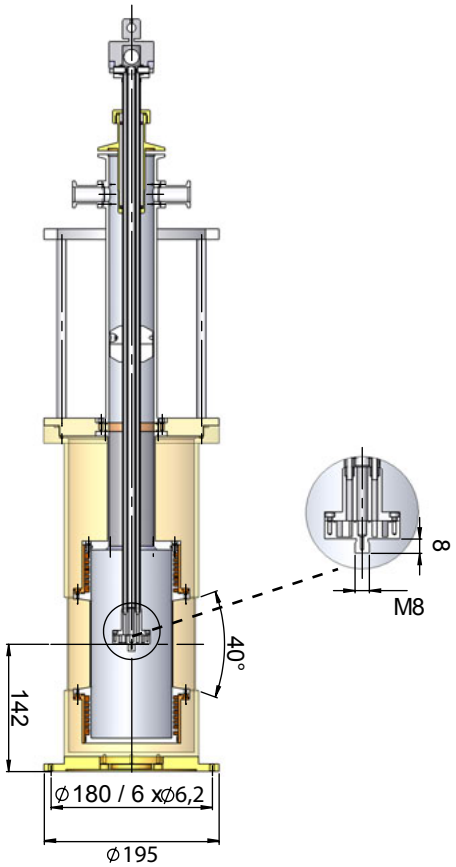


Figure 4: Cut through the CTF Circulation thermostat furnace.

Dr. Jürgen Peters

Phone: +49.(0)89.289.14700
Email: juergen.peters@frm2.tum.de

LT

low temperatures

The FRM II sample environment group supplies a variety of liquid refigerant free cryostats adapted for the different needs on the FRM II instruments. Besides standard closed cycle cryostats, either of toploading type or sample directly mounted to coldhead, adapted versions for the use inside the vertical field 7.5 T magnet system, the 40 kN press or equiped with a thermoswitch for temperatures above RT are available. For special requirements please contact the sample environment group or your local contact to discuss details.

CCR - closed-cycle cryostat with sample tube

The liquid refrigerant free closed cycle cryostats of the CCR-type are designed for a fast change of samples. They are based on pulse-tube technique refrigerators with a 6 kW water cooled compressor unit. The sample tube is connected to the pulse tube cold plate with a copper heat exchanger.

The sample tube is filled with exchange-gas. Temperature regulation is achieved by a sensor and a heater attached to the sample tube. The sample-holder is in general mounted to a sample stick (see figure 2). Temperatures ranging from 3.5 K to RT can be regulated. To reach for temperatures above RT to 700 K the sample space has to be evacuated and a special high-temperature sample-stick has to be used. For this case temperature control is provided by a heater and sensor mounted on the sample stick.

Common features

- Based on pulse-tube refrigerator
  cooling power 2nd stage:
  400 mW (design 2002)
  1000 mW (design 2009)
- 1 radiation shield connected to 1st stage
- Temperature sensor Cernox® 1,4 K – 325 K
- Heater 25 Ω / 100 W
- Temperature range:
  with exchange gas in sample space
  2,8 K – 300 K (CCR 9 – 11; design 2009)
  3,5 K – 300 K (CCR 1 – 8; design 2002)
- Extended temperature range:
  evacuated sample space and HT sample stick
  T < 700 K (all devices)
- Typical cool down times of the cryostat
  RT to base temperature
  min. 4 h (CCR 1 – 8)
  min. 2,5 h (CCR (9 – 11)
- Cool down time for sample change with cryostat at base temperature < 1.5 h

Dimensions

- Diameter sample space:
  < 50mm (CCR 1 – 7, 9 –11)
  < 80mm (CCR 8)
- height of sample space (beam window):
  approx. 75 mm

Available Sample Sticks

- Standard stick (T < 300 K)
- High temperature stick (T < 700 K)
- Rotation sample stick to provide sample rotation with fixed cryostat position (for example in the CCM vertical field magnet)
- Gas adsorption stick

The sample position in the beam can be adjusted by a simple height adjustement at the bottom part of the sample stick

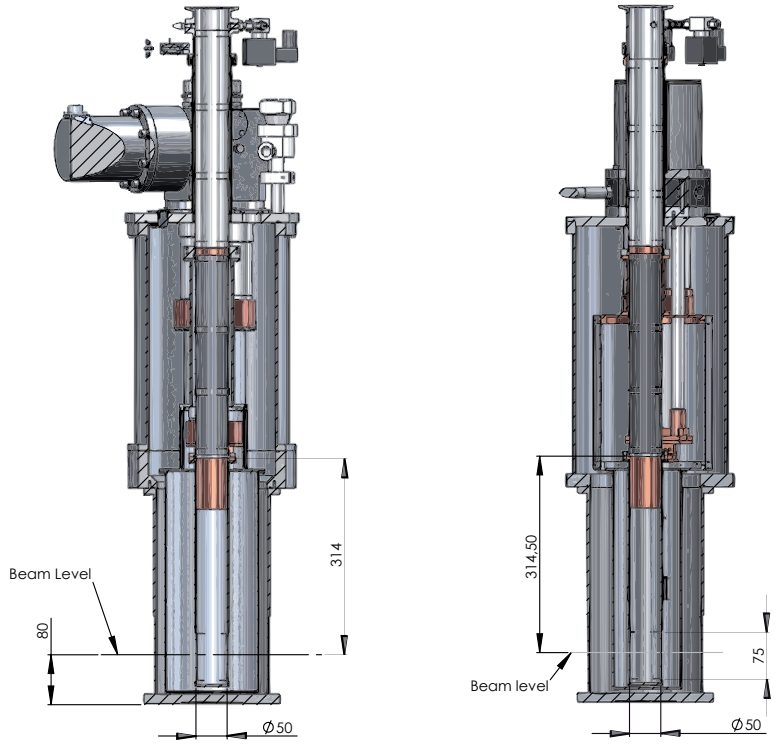


Figure 1: cut through CCR cryostats CCR 9,10,11 (design 2009) and CCR 1 – 7 (design 2002)

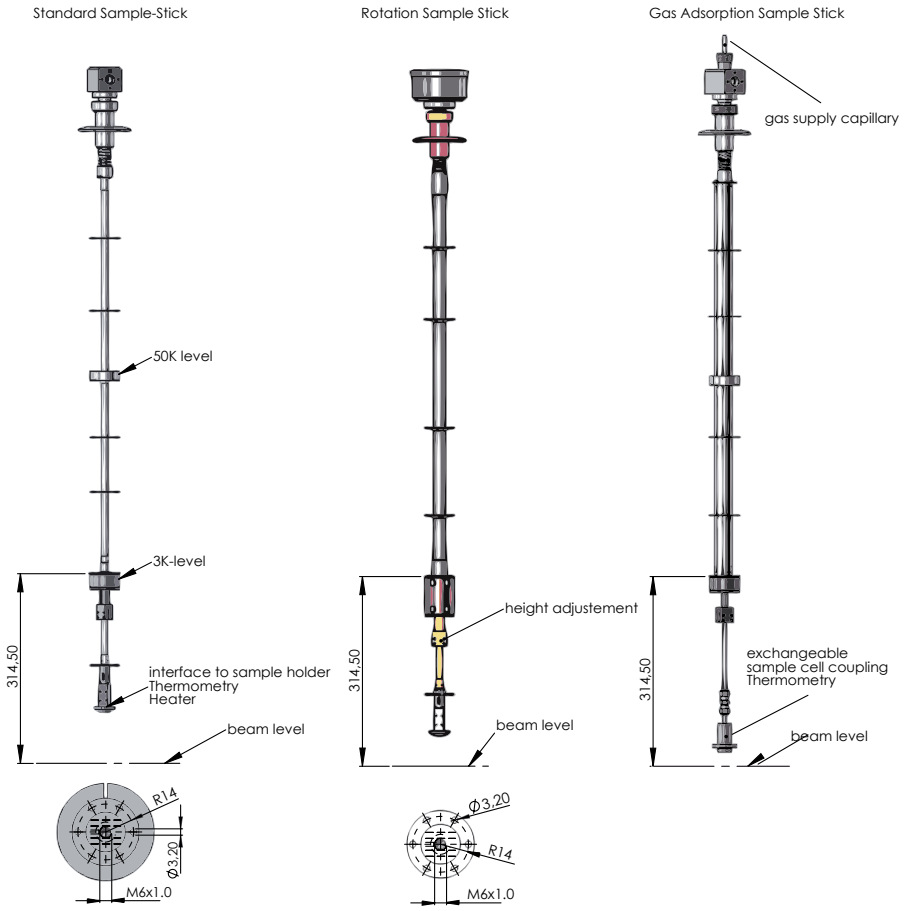


Figure 2: Sample Sticks provided for CCR cryostats

Dr. Jürgen Peters

Phone: +49.(0)89.289.14700
Email: juergen.peters@frm2.tum.de

CCI - low temperature inserts

To reach temperatures below 3 K ^{3}He and ^{3}He / ^{4}He insert cryostats for the CCR systems are available. Please note an additional preparative time of up to 4h is needed before first cool-down.

CCI spezifications

	CCI - ^{3}He	CCI ^{3}He/^{4}He
Temp. range	450 mK – 10 K	50 mK – 1 K
Cooling power	1 mW (500 mK)	15 µW (100 mK)
Heater	10 Ω	10 Ω
Cool-down time	5 h	7 h
Sample Ø	30 mm	30 mm
Sample space-height	145 mm	70 mm
Distance cold plate to beam level	106.5 mm	27 mm

CC- closed-cycle cryostats

The closed cycle cryostats of the CC-type are based on SHI-RDK-2025D and SHI-RDK-101D cold-heads mounted with differing isolation vaccum tails. The sample space of these liquid-cryogen free closed-cycle cryostats is inside the isolation vaccum. The thermalisation of the sample is achieved by the thermal conductivity of the sample holder and the cold-plate. The temperature sensor for temperature control is mounted on the cold-plate. To avoid temperature gradients a sample mounting with adequat thermal conductivity is needed. In case of sample with poor thermal conductivity, the usage of an exchange-gas (He) containing sample can or the use of a CCR-type cryostat should be considered.

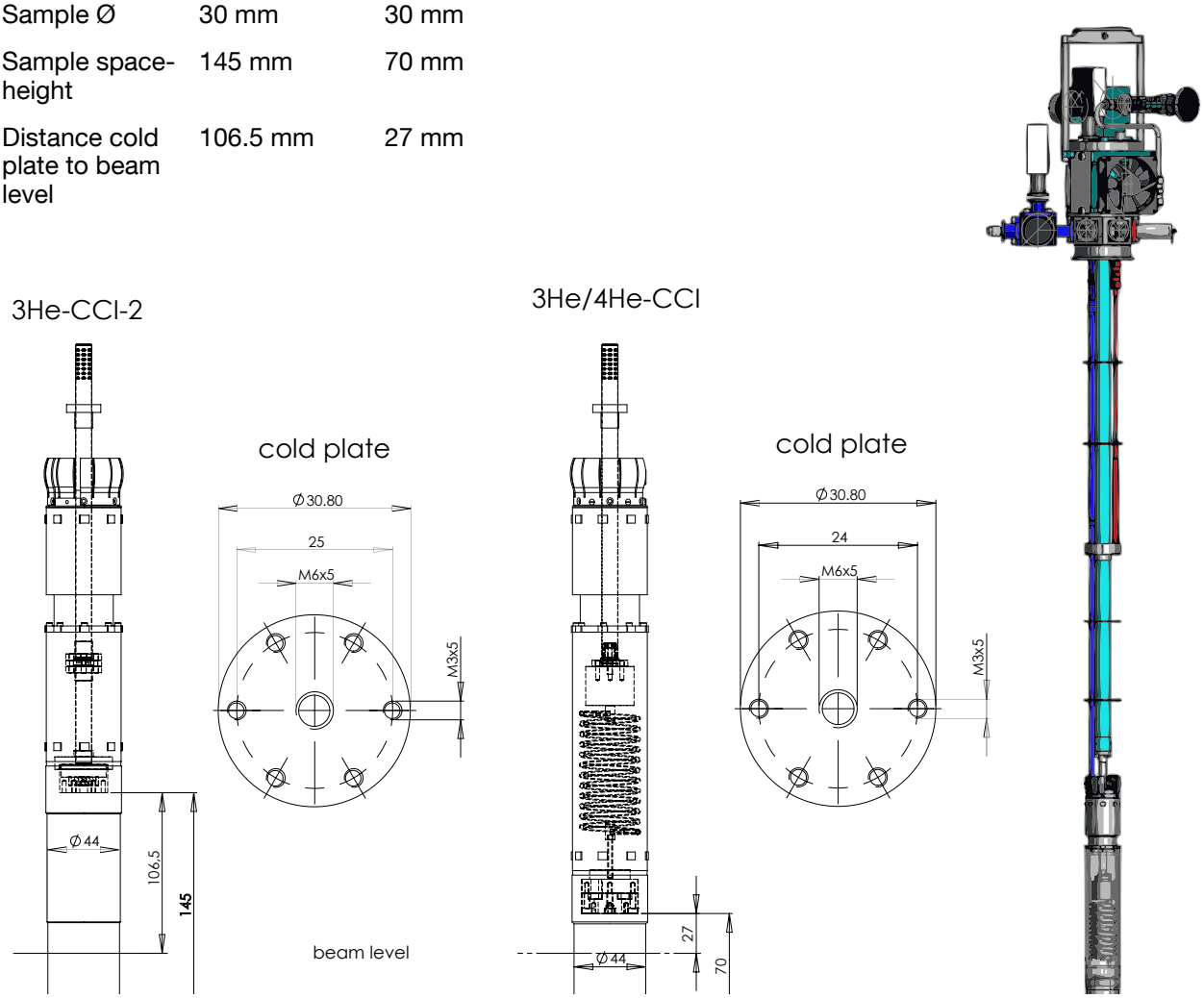


Figure 1: cut through the CCI inserts

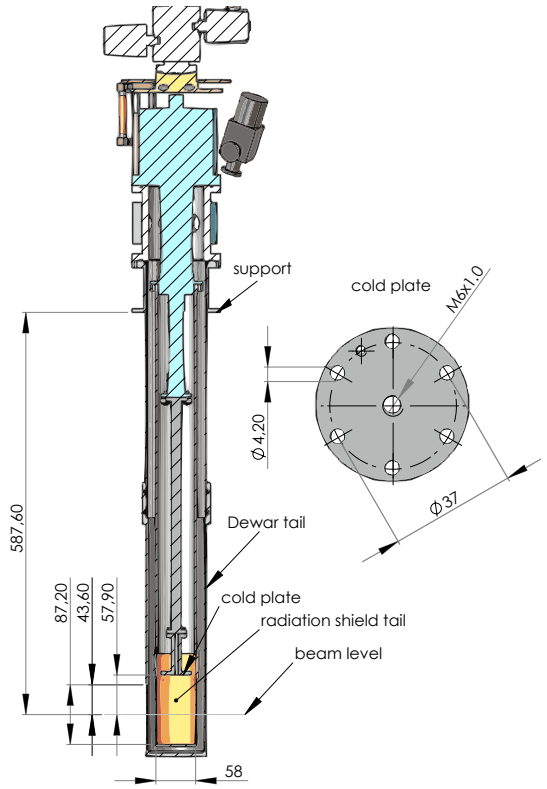


Figure 2: cut through CC-5 / CC-6

CC-1*, CC-2-PUMA, CC-3, CC-4-PANDA

Standard crysostat; based on SHI-RDK-2025D

- Temperature range: 2,8 K – 300 K
- Cooling power 2. stage: 250 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1,4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2,8 K: 2,5 h
- total height of sample space: 110 mm
- diameter of sample space: 60 mm

* CC-1 prepared for the condensation of non-corrosive gases up to P = 100 bar

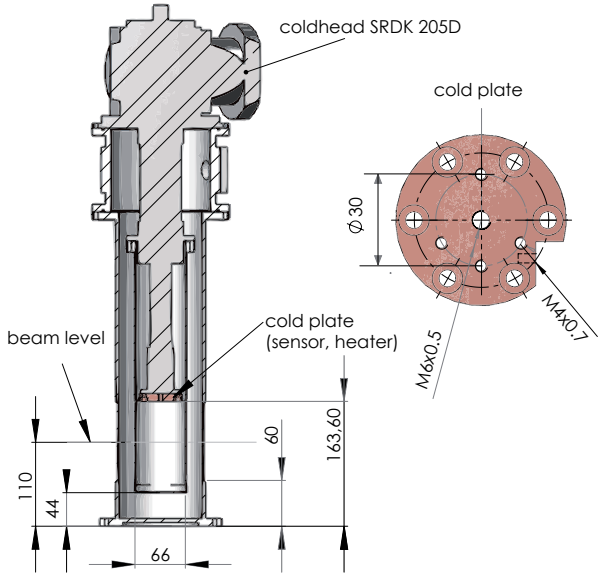


Figure 3: cut through CC-3

CC-5, CC-6

Based on SHI-RDK-101D; prepared for use in Eulerian cradle.

- Temperature range: 2,2 K – 300 K
- Cooling power 2. stage: 110 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1,4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2,8 K: 2 h
- sample space: Ø 10 mm, height 10 mm

CC-7-CCM

Based on SHI-RDK-101D; prepared for use in 7.5 T vertical magnet.

- Temperature range: 2,2 K – 300 K
- Cooling power 2. stage: 110 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1,4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2,8 K: 4 h
- sample space: Ø 55 mm, height 85 mm

CC-8, CC-9-RESEDA,CC-10-PUMA

Based on SHI-RDK-101D; with high temperature option.

- Temperature range: 2,8 K – 600 K
- Cooling power 2. stage: 110 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Pt1000 IST 10 K – 600 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2,8 K: 3 h
- Cool-down time 600 K – 2,8 K: 5 h
- total height of sample space: < 136 mm (< 85 mm CC-9 / CC-10)
- diameter of sample space: < 138 mm (< 55 mm CC-9 / CC-10)

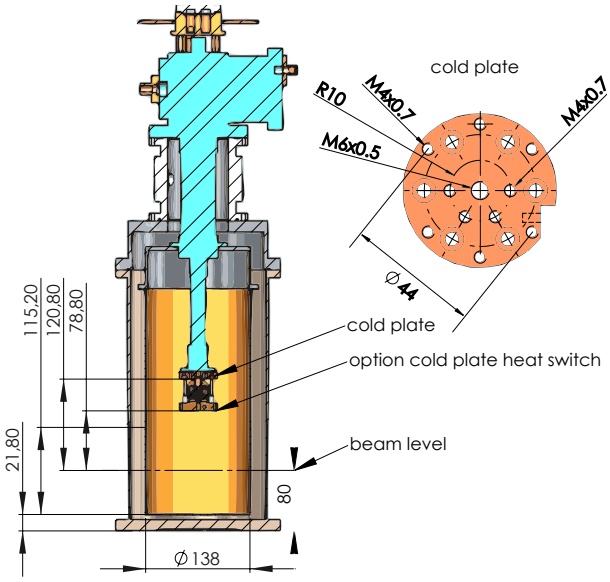


Figure 4: cut through CC-8

Dr. Jürgen Peters

Phone: +49.(0)89.289.14700
Email: juergen.peters@frm2.tum.de

HP

high pressure

HPG - 10kbar

To load gas pressure cells FRM II provides a gas compression unit for inert gas pressure up to 10 kbar. The unit can be oprerated either manually or remote controlled. The remote controlled operation allows for individually programmable pressure time profiles. The measurement system includes a high-precision manometer and a pressure transmitter that cover the range up to 10 kbar.

HP 400kN press

A special challenge is to go to low temperatures at high pressures. The newly constructed high-pressure cryostat allows one to apply and vary the force in situ, even at low temperature. The sample cell is operated externally by a hydraulic press with 450 kN compressive force and 220 kN repulsive force. It can be mounted in a dewar and cooled down to below 20 K within four hours. With a piston-in-cylinder cell and a piston diameter of 16 mm a maximum pressure of 2.0 GPa (20 kbar) can be achieved at a sample size up to 30 mm length and 16 mm diameter. Reducing the piston diameter and the sample volume the pressure can be increased up to 100 kbar. Using anvil cells the pressure range extends to 30 GPa (300 kbar) and above. In addition, a dynamic pressure can be superimposed on the static pressure with a frequency of up to 10 Hz. The amplitude depends on the elasticity of the sample and the indenters. At 10 Hz and without load the amplitude of the sinusoidal movement of the hydraulic piston amounts to 1.0 mm and is inversely proportional to the frequency. That is, at a frequency of 1.0 Hz or below the dynamic range approximates the static pressure range.

HPG-10kbar spezifications

- Pressure range 10^5 Pa ≤ p ≤ 10^9 Pa

Pressure measurement:

- 10^5 Pa ≤ p ≤ $7 \cdot 10^8$ Pa Heise high-precision manometer; resolution 0.1% ME
- $7 \cdot 10^8$ Pa ≤ p ≤ 10^9 Pa transmitter; resolution $9 \cdot 10^6$ Pa

CC-11-P / HP 400kN

Closed cycle cryostat adapted to be used with the HP 400kN press.

- Temperature range: 20 K – 600 K
- Cooling power 2. stage: 1.5 W
- number of radiation shields: 1
- Thermometry: Cernox
- Heater cartridge 25 Ω / 100W
- Cool-down time RT – 20 K: 4 h
- Sample space: max Ø16mm, height 10mm
- Pressure range: 200MPa for Ø16mm anvil

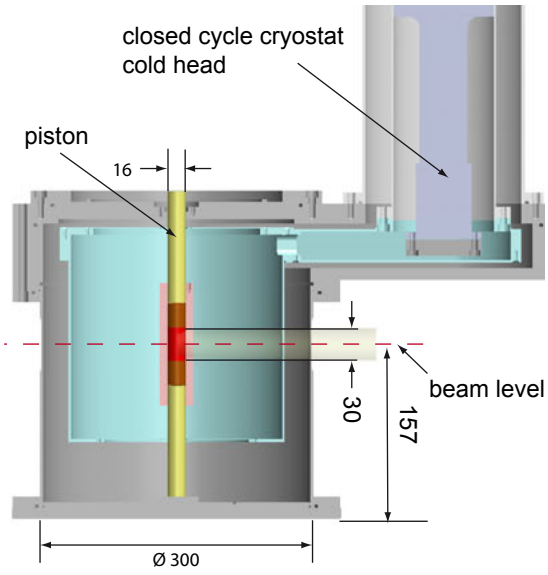
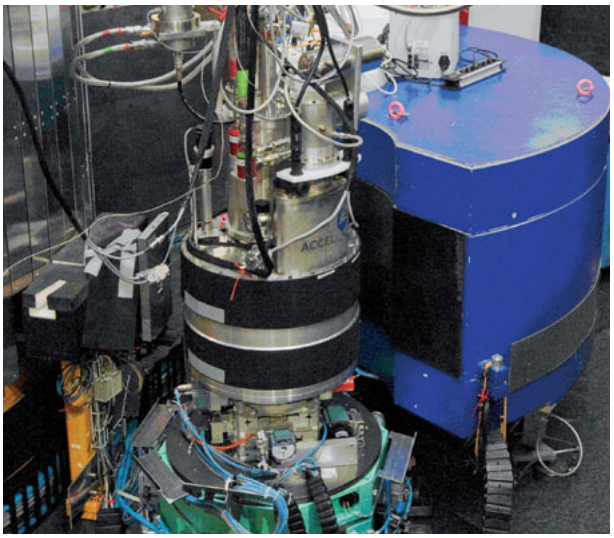


Figure 1: Cut through CC-11-P

MF

magnetic field



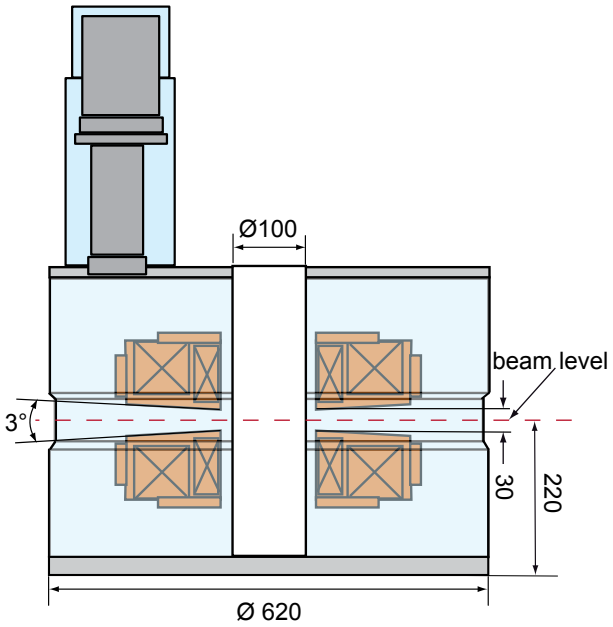


Figure 1: Cut through CCM - 7.5T

CCM - 7.5T

The CCM - 7.5T is a liquid cryogen free superconducting, vertical field magnet with a room temperatur bore of 100 mm. Various inserts such as closed-cycle cryostats of the CC or CCR type, even including the low temperature inserts and pressure cells or the dedicated versions of the HTF furnace make this magnet a versatile tool, allowing the combination of differing external parameters during one experiment.
Using a precision rotary table mounted on top of the magnet, other sample environment equipment such as cryostats can be rotated around the vertical axis with an angular resolution of 0.005 degree.

CCM-7.5T

- Maximum magnetic field: ± 7.5 T
- Homogenity of the magnetic field (Ø 15 mm sphere): 0.2%
- Room-temperature bore: Ø 100 mm
- Beam window dimensions:
  vertical gap: 30 mm
  vertical open angle: 3°
  in plane open angle: 320°
- Total thickness of Al in the beam: 30 mm

A dedicated 13.5 T vertical cryomagnet (Oxford Instruments) including a low temperature insert for temperatures down to 50 mK is available at the instrument PANDA, see the PANDA page for details.

Dr. Jürgen Peters

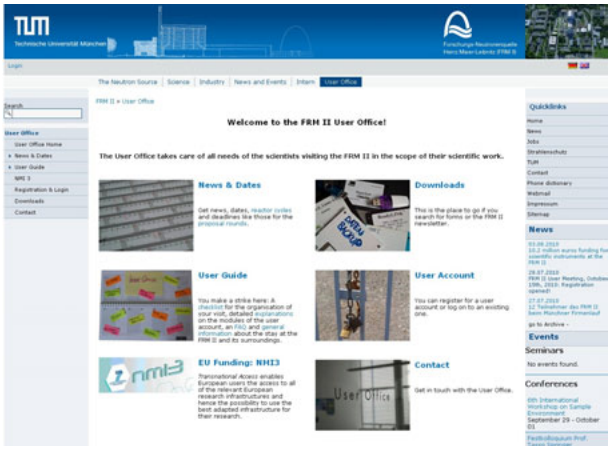
Phone: +49.(0)89.289.14700
Email: juergen.peters@frm2.tum.de


MUT
LOGISTIKKOMPETENZ
ulrich
MUT

User office

General information for users

The User Office is the administrative unit for the organization of the scientific use of the FRM II. The office is a joint venture of the FRM II and the JCNS on-site. It takes care of everything scientists have to deal with visiting the neutron source in the scope of their work. First contact with the User Office is done in general via the web pages:



www.frm2.tum.de/user-office

Available information:

- Reactor cycles and proposal deadlines
- Workflow description
- Requirements for the access to the site
- Radiation protection regulations
- Accommodation
- Possibilities for financial support
- Download area with forms and templates for proposals and reports.

User Office online

The essential communication tool for all issues of a scientific application is the online User Office, which can be found at:

user.frm2.tum.de

or similar for JCNS at:

fzj.frm2.tum.de

In order to apply for beam time at one of the instruments at FRM II, first of all the user has to create an account at the online User Office. Those sites have a common user database, i.e. one account serves for both entries. By means of their account the users have access to appropriate web tools for the submission of proposals for beam time and of experimental reports and EU-reports.

How to get beam time for scientific experiments

Prior to writing the proposal we strongly recommend to contact one of the instrument responsibles to discuss the feasibility of the project. Proposals may be submitted any time – twice a year the User Office organizes a call with deadline for the refereeing process.

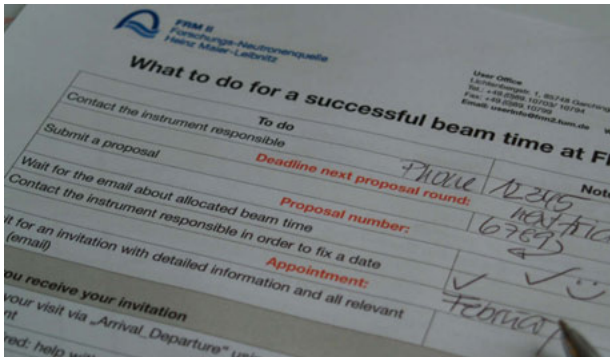
Beam time and usage of the instruments at the FRM II are free of charge for nonproprietary scientific research. This is valid under the obligation that the results are published in scientific journals or presented at conferences. Currently more than 250 applications are submitted on each call for proposals from Germany, Europe, and abroad.

The submitted proposals are checked under several criteria. Both the radiation protection and general safety aspects are approved by the respective departments at the FRM II. In addition the instrument scientist has to confirm the technical feasibility of the experiment at the chosen instrument.

After this procedure the remaining proposals are reviewed by an international scientific panel within two months of each proposal round's deadline. The panel currently consists of five sub-committees, whose members are from universities and research institutions from all over Europe. The individual sub-committees cover the different scientific fields as magnetism and phonons, structure research, soft matter, thin films and biology, nuclear and particle physics as well as positrons and finally with materials research and radiography.

During a meeting at the FRM II these committees rank the proposals according to their scientific merit and suggest the distribution of the available beam time to the director of the FRM II. On average, two-thirds of the submitted applications receive beam time, i.e. about 50 % of the requested beam days can be accepted.

Shortly after the committee meeting the user gets



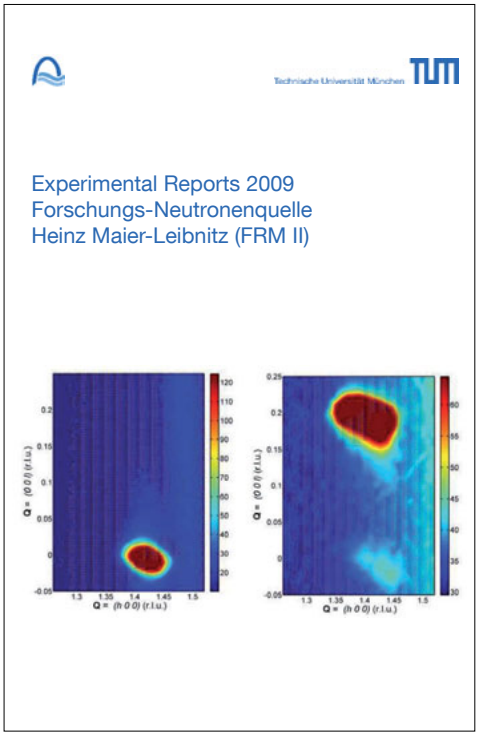
notified, if his proposal was accepted or not. If the application was approved, the next step is to contact the instrument scientist immediately in order to schedule the experiment.

When the date for the experiment is set, the User Office sends out a detailed invitation letter to the main proposer by email. This letter also informs about who will support the experiment as local contact. As soon as possible each scientist, who wants to participate in the experiment has to announce his visit online to the User Office. An early announcement enables the smooth access to the FRM II. Within this procedure it is also possible to ask for assistance reserving a hotel room. The User Office can not give any help concerning flights or train tickets.

Publications and experimental reports

After performing the experiment at an FRM II instrument we kindly request the submission of an experimental report. Failure to do so may lead to rejection of subsequent proposals. All experimental reports are archived and accessible via the web within the personal user account. Every year the reports of the previous year are published as a pdf document on the web pages of the FRM II.

The FRM II expects that the local contact in charge of the proposal is involved as coauthor in publications mainly dealing with the results of the experiment. Furthermore users are obliged to notify their



local contacts about any publication of the results achieved at the FRM II. Please keep in mind, that without his help during the measurement and providing the instrument the experiments would not be possible. In addition a note indicating the support received from the FRM II, JCNS or other institutions should appear in the acknowledgement of any publication.

Financial support

FRM II and JCNS are members of the network of European neutron facilities NMI3 (“Integrated Infrastructure Initiative for Neutron Scattering and Muon Spectroscopy”).

The EU funds provide free access to the facility and provide support for travel and subsistence expenses for, typically, one scientist per experiment. This applies for users working at institutions or universities in a European state or an associated country other than Germany.

If a proposal is financially supported by the EU via NMI3, the user has to send the claim for travel expenses with all necessary receipts as well as the user data form to the User Office and submit the EU-report online in addition to the routine experimental report.

Access to the FRM II

Certain points need particular attention when visiting the FRM II For access, a valid passport or ID-card is required. Driving licenses or other personal documents are not sufficient!

Security regulations

For users working at German facilities and institutions a nuclear reliability check will be performed in order to facilitate the access to the experimental hall. This check is not necessary for working only in the neutron guide hall. The declaration form has to be completed and signed and the original send by post to the FRM II. The check will be organized by the FRM II authorities. Please note that this will take up to 2-3 months! Independent of the status of the nuclear reliability check the access to the experiment will be possible at any time. Without a valid security clearance, however, the user will be checked by the security when entering the experimental hall.

The declaration form can be obtained from the download area of the User Office. If a nuclear reliability check exists due to previous visits at other nuclear facilities in Germany, this has to be indicated in the declaration form.

Radiation protection

In order to comply with the official rules of radiation protection, each user must follow strictly the regulations adapted to the FRM II. Details are given in the frequently asked questions (faq) section of the User Office web pages.

There are different regulations for users working at German institutions and scientists from abroad. The latter are additionally subdivided into those who are radiological workers and those who have never worked in a controlled area before. For both categories there are forms available at the User Office download area. The completed and signed documents have to be presented to the radiation protection department at the FRM II prior to start an experiment.

Important for German users: They need a “Strahlenpass” (radiation passport) with dose records not older than three months. They have to carry their own dosimeter (capable of detecting neutrons and gamma radiation). In addition their home institution needs a valid license according to §15 StrlSchV as well as an ‘Abgrenzungsvertrag’ (contract with TUM defining responsibilities of radiation protection departments).

To learn more about the current regulations, please look at the web pages of the radiation protection department.

Arriving at the FRM II

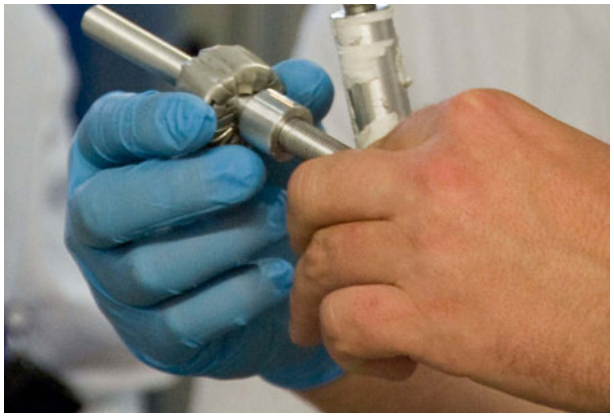
The reception at the entrance gate will be the first place to go. Here the users will get their process slips and additional useful information. Also the personal badge valid for this stay will be issued. This badge and the completed process slip have to be returned upon departure. The local contact will be informed about the arrival. Before starting the measurements, everybody has to enrol at the radiation protection office. There, one has to prove that the safety training was undergone. If this is the first

visit at the FRM II or it is more than one year since the last safety training one has to complete it first before starting to work.

Please keep always in mind, that those regulations are subject to change without prior notice. The web pages of the User Office provide all users always with the latest information.

Sample handling

Any sample or material brought into the experimental hall and the neutron guide hall must be checked by the radiation safety department for clearance be-



fore removal from the areas. Special attention must be paid, if an already activated sample is brought along. Please inform your local contact in advance and declare this sample during the check-in at the radiation protection service.

Terminal room

A terminal room is available on site allowing users to have access to the internet as well as the possibility to control experiments remotely and access data. Details on the access to the terminal room are provided by the local contact.

Conferences and meetings

Every 18 months the FRM II invites all users to the FRM II User Meeting held in Garching. The meeting is organized in order to discuss recent scientific results presented by the user community. Moreover the FRM II provides updated information concerning the instruments and experimental possibilities.

Workshops on different topics related to the use of neutrons are organized by FRM II and JCNS regularly. Announcement will be published on the Internet pages, see “News and Events” and in the biannual newsletter.

The FRM II and JCNS participate in national and international conferences on neutron scattering. Besides contributions about recent scientific achievements, updated information on the instruments and available infrastructure are presented.

Dr. Thomas Gutberlet

Phone: +49.(0)89.289.10703
Email: t.gutberlet@fz-juelich.de

userinfo@frm2.tum.de

Dr. Ina Lommatzsch

Phone: +49.(0)89.289.10794
Email: ina.lommatzsch@frm2.tum.de

www.frm2.tum.de/en/user-office

Partner institutions

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Georg-August-Universität Göttingen
Institut für Physikalische Chemie
Tammannstraße 6
37077 Göttingen
www.uni-pc.gwdg.de/eckold/
Geowissenschaftliches Zentrum
Goldschmidstraße 1-3
37077 Göttingen
www.gzg.uni-goettingen.de

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Festkörperphysik
Heisenbergstraße 1
70569 Stuttgart
www.fkf.mpg.de

HZB Helmholtz Zentrum Berlin

Helmholtz Zentrum Berlin
für Materialien und Energie
Hahn-Meitner-Platz 1
14109 Berlin
www.helmholtz-berlin.de

JCNS Jülich Centre for Neutron Science

Jülich Centre for Neutron Science JCNS
Forschungszentrum Jülich GmbH
52425 Jülich
Außenstation am FRM II: 85747 Garching
www.jcns.info

der Bundeswehr Universität München

Universität der Bundeswehr München
Institut für Angewandte Physik und Messtechnik
Werner-Heisenberg-Weg 39
85577 Neubiberg
www.unibw.de/lrt2/

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Ludwig-Maximilians-Universität München
Sektion Kristallographie
Theresienstraße 41
80333 München
www.lmu.de/kristallographie

Sektion Physik
Schellingstraße 4
80799 München
www.softmatter.physik.uni-muenchen.de

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

Helmholtz-Zentrum Geesthacht,
Zentrum für Material- und Küstenforschung
Max-Planck-Straße 1
21502 Geesthacht
www.hzg.de

RWTH AACHEN UNIVERSITY

RWTH Aachen
Institut für Kristallographie
Jägerstraße 17 - 19
52066 Aachen
www.xtal.rwth-aachen.de

Institut für Anorganische Chemie
Landoltweg 1
52074 Aachen
www.ac.rwth-aachen.de

TU Clausthal

Technische Universität Clausthal
Institut für Werkstoffkunde und Werkstofftechnik
Agricolastraße 6
38678 Clausthal-Zellerfeld
www.iww.tu-clausthal.de

TECHNISCHE UNIVERSITÄT DARMSTADT

Technische Universität Darmstadt
Fachbereich Material- und Geowissenschaften
Petersenstraße 23
64287 Darmstadt
www.tu-darmstadt.de/fb/matgeo/

TECHNISCHE UNIVERSITÄT DRESDEN

Technische Universität Dresden
Institut für Festkörperphysik
Zellescher Weg 16
01069 Dresden
www.physik.tu-dresden.de/ifp

Universität Augsburg
University

Universität Augsburg
Institut für Physik
Lehrstuhl für Chemische
Physik und Materialwissenschaften
Universitätsstraße 1
86159 Augsburg
www.physik.uni-augsburg.de/cpm/

Universität zu Köln

Universität zu Köln
Institut für Kernphysik
Zülpicher Straße 77
50937 Köln
www.ikp.uni-koeln.de

II. Physikalisches Institut
Zülpicher Straße 77
50937 Köln
www.ph2.uni-koeln.de

Excellenzcluster Origin and Structure
of the Universe
Boltzmannstr. 2, 85748 Garching
www.universe-cluster.de

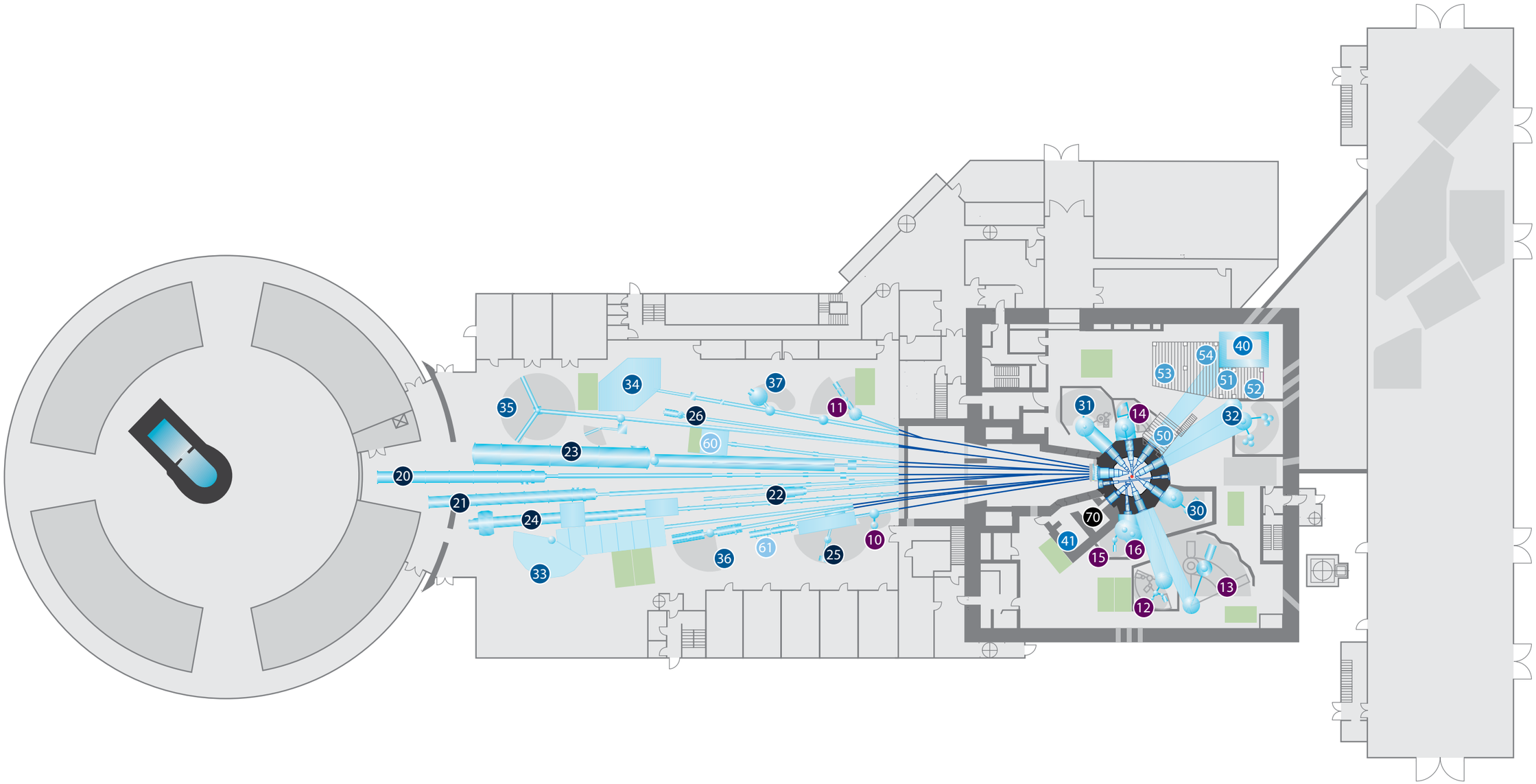
Lehrstuhl für Experimentalphysik IV, E13
James-Franck-Str. 1, 85748 Garching
www.e13.physik.tu-muenchen.de

Lehrstuhl für Experimentalphysik I, E18
James-Franck-Str. 1, 85748 Garching
www.e18.physik.tu-muenchen.de

Lehrstuhl für Experimentalphysik III, E21
James-Franck-Str. 1, 85748 Garching
www.e21.physik.tu-muenchen.de

Lehrstuhl für Radiochemie
Walther-Meissner-Str. 3, 85748 Garching
www.radiochemie.de

Klinikum rechts der Isar
Klinik und Poliklinik für Strahlentherapie und Radiologische Onkologie
Ismaninger Str. 22, 81675 München
www.radonc.med.tu-muenchen.de



DIFFRACTION

12	RESI	p. 16
15	HEIDI	p. 18
16	POLI	p. 20
13	SPODI	p. 22
14	STRESS-SPEC	p. 24
10	BIODIFF	p. 26
11	MIRA	p. 28

SANS and Reflectometry

20	KWS-1	p. 32
21	KWS-2	p. 34
22	KWS-3	p. 36
23	SANS-1	p. 38
24	REFSANS	p. 40
25	N-REX+	p. 42
26	MARIA	p. 44

Spectroscopy

30	PUMA	p. 48
31	PANDA	p. 50
32	TRISP	p. 52
33	TOFTOF	p. 54
34	SPHERES	p. 56
35	RESEDA	p. 58
36	J-NSE	p. 60
37	DNS	p. 62

Imaging

40	ANTARES	p. 66
41	NECTAR	p. 68

Nuclear- and Particle Physics

60	PGAA	p. 80
61	mephisto	p. 82

Positrons

50	NEPOMUC	p. 72
51	CDBS	p. 74
52	PAES	p. 75
53	PLEPS	p. 76
54	SPM	p. 77

70 MEDAPP

Imprint

Publisher

Board of Directors
Forschungs-Neutronenquelle
Heinz Maier-Leibnitz (FRM II)
Technische Universität München
Lichtenbergstr. 1
85748 Garching
Germany
Tel: +49.(0)89.289.14966
Fax: +49.(0)89.289.14995
Email: frm2@frm2.tum.de
www.frm2.tum.de

Editors

Dr. Jürgen Neuhaus
Dr. Ina Lommatzsch
Andrea Voit

Editor-in-chief

Dr. Peter Link

Design

Dr. Peter Link
Dr. Ina Lommatzsch
Benjamin Sanchez

Picture credits

Ulla Baumgart: 4
Andreas Heddergott / Astrid Eckert, TUM: title image, 5, 50, 66,
Wenzel Schürmann, TUM: 16, 18, 24, 32, 34, 38, 40, 42, 48, 52, 60, 62, 68, 70, 72, 80, 87, 88, 93, 100, 107

other images: editors, authors, TUM

schematic illustrations of the instruments:
Ramona Bucher, Julia Fridgen, Christine Sturz, Medienlabor des Physikdepartments, TUM
Dr. Peter Link